A HUNDRED YEARS
OF
GERMAN BRIDGE BUILDING

BY

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PUBLISHED FOR THE PARIS UNIVERSAL EXHIBITION 1900

BY ORDER OF THE FIRMS

MASCHINENFABRIK ESSLINGEN IN ESSLINGEN
GUTEHOFFNUNGSHÜTTE, AKTIENVEREIN FÜR BERGBAU UND HÜTTENBETRIEB IN OBERHAUSEN
GESELLSCHAFT HARKORT IN DUISBURG AM RHEIN
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WERK NÜRNBERG (ZWEIGANSTALT GUSTAVSBURG)
UNION, AKTIEN-GESELLSCHAFT FÜR BERGBAU, EISEN- UND STAHL-INDUSTRIE
IN DORTMUND

TRANSLATED FROM THE GERMAN

BY

LUDWIG MERTENS C. E.

WITH 195 ILLUSTRATIONS

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Preface.

At the Paris Universal Exhibition of 1900 it is intended to demonstrate the advance in iron bridge construction by a joint exhibition arranged by six of the leading German firms, viz.: The *Esslingen* Engine Works at Esslingen — the *Gutehoffnungs Works* (Mining and Metallurgical Company, Ld., at Oberhausen, Rhine Province) — the *Harkort* Company at Duisburg-on-Rhine — Messrs. *Phil. Holzmann* & Co., Ld., at Frankfort-on-Main — the United Engine Factories of *Augsburg* and *Nuremberg* (Gustavsburg Branch) and the *Union Works*, Mining, Iron and Steel Company, Ld., at Dortmund, Westfalia. At a conference held in May 1898 at Frankfort-on-Main, it was resolved to illustrate the entire field of German bridge construction by means of paintings, models, pamphlets, catalogues, working drawings and photographs. Besides, it was decided to publish a special work in German, French and English, treating the *development of bridge construction with regard to theory, design and erection,* supplemented by a description of the objects on view.

The author, being intrusted with the edition of this work, begs to tender his sincere thanks to the firms named above for the valuable information supplied to him concerning the history and the production of their respective etablishments. At the same time he cannot refrain from giving expression to the wish that the cooperation of men representing German industry and science, which formed so gratifying a feature of the latter part of the nineteenth century, culminating in the magnificent gift presented by German manufacturers to the technical colleges at the occasion of the Berlin centenary festivals, may continue to be of immense benefit to all branches of engineering during the coming century.

If the scope of the present work, relating to the development of *German* bridge building, has been somewhat exceeded in places, this may be excused by the desire of providing a suitable background for the subject specially treated, on the one hand by characterising the past century as a whole from an engineer's point of view, making occasional excursions into the domain of metallurgy, on the other by contrasting the present with the past, as well as German with foreign work.

500 copies only of the German edition of this work will be sold; during the Paris exhibition one thousand more of each of the three editions will be presented by request to engineers interested in the subject. The author takes this opportunity of expressing his thanks to *Baurath Peters,* of the Society of German Engineers, who has kindly agreed to publish the paper in the widely read Journal of that Society.

Besides he is under particular obligation to the gentlemen who in various ways have assisted him in the publication, viz. for the English edition: to Mr. *Ludwig Mertens* C. E., of Hamburg, and Mr. *Leo Backhaus,* chief manager of the Harkort Company; for the French edition: to Mr. *Oscar Ihro* C. E., of Sterkrade, and *Professor Krohn,* chief manager of the Gutehoffnungs Works.

Finally a grateful word of acknowledgement is due to the publishing firm of *Julius Springer,* Berlin, for the great pains taken in bringing out all three editions of the work with promptness and in capital style.

Dresden, March 1900.

Contents.

I.

Introduction.

1. THE NINETEENTH CENTURY. The evolution of mankind proceeds in unceasing change of life and events, unheeding the coming and going of centuries. But in the history of peoples the time limit of centuries, fixed by human hand, forms convenient steps, from which to survey and estimate the march of progress. Thus at the present moment men prominent in many fields of human knowledge and work are weighing the spiritual and material attainments of the parting century, and we are already being flooded with a copious literature concerning its promises and performance. Varying according to the point of view taken and the profession of the commentator, the nineteenth century appears before our eyes in as many different lights and characters. This is already proved by the number of different designations bestowed on it, from "the century of natural philosophy"—of races—of nationalities—of socialism—of the press—to the "century of women", which one and all fail to characterize it in its entirety, each showing only part of the picture.

The most significant feature of the nineteenth century is to be found not so much in its ideas, as in its material attainments. A long series of technical inventions in every branch of industry and trade has revolutionised the entire economical conditions of our globe in a manner more radical than ever happened before. The result during the first half of the century showed itself in a complete reversal of political power, accompanied by a prodigious industrial revival and the rise of an immense army of working men, in contrast to a distinct set back to agriculture in all its branches. In connection with these and other facts, the solution of urgent social questions, as they have gradually made their appearance, is to be left to the coming century.

In the course of the century technical inventions have been organising *human labour* in a manner hitherto unheard of, so that to-day it encircles the globe with a million threads, making its action felt within the humblest of human abodes. Labour and trading are in constant correlation. Thus the division of labour has more and more become a charm, by which to clear away all obstacles before the restless stream of trade and to open new paths to it in all parts of the world. And if according to a striking saying of the German emperor, the world at the end of the century "stands in the sign of trade", this is due above all to those great engineering inventions, which have given to our age not only the blessings of work, but with it the best means of becoming "better and happier".

First to be mentioned is a series of revolutionizing inventions, forming in their union the foundation for the rise of the *locomotive railway.* Their beginnings date back as far as the eighteenth century, which kept hidden in its soil, prepared for ages, the corner stones of engineering work for coming centuries. In English metallurgy water power was replaced by *steam power* and charcoal by *pit-coal,* resulting in a considerable improvement of the pig iron within the blast furnace and inducing the adoption of cast iron as a constructive material in place of timber and stone. It was, however, only between 1820 and 1830 that the whole of these inventions were brought to maturity. After, about this time, *puddled iron* had been generally substituted for cast iron and—to make use of Stephenson's expression—"locomotive and iron railway had learned to behave like husband and wife", the hour of birth of the first locomotive railway had arrived. It need not be repeated here, how the railways, springing into existence, at once commenced to consume prodigious quantities of the new material, inducing thereby its metallurgical production in bulk, how further iron industry and railways, mutually raising and supporting each other, continued to grow in size and strength, without ever making a pause, up to the present moment. This phenomenon indeed forms the most striking example of the correlation between labour and commercial intercourse referred to, a golden spring from which all improvements in the spiritual and material life of peoples take their origin.

Beyond doubt the nineteenth century from beginning to end carries the stamp of engineering, and in providing it with a characteristic name this fact ought to be given expression to. The nineteenth century is the *"century of engineering"*, the foundation for which was laid during that memorable time, when coal and iron formed their union with steam, when guided by *analytical chemistry* the science of metallurgy originated, when the first great

technical colleges were being founded. At the same time, indeed, it is an *iron century*, because at no period during past ages has iron served all works of peace and war with so uniform and overpowering a success than during the century just passed away.

Even at its beginning many people had become aware that the standard of culture attained by a people can be measured by its consumption of iron. Fourcroy, the analytical chemist[1], whom Napoleon I in 1801 made his minister of education, said: "L'art de fer dans ses divers progrès de perfectionnement marque exactement le progrès de toute civilisation". And Napoleon himself, who clearly recognised the high importance of the English inventions and innovations of that period, though, hating everything English, he at the same time delayed their introduction to the Continent of Europe for some dozens of years by means of the great blockade, in a proclamation dated the 8th of March 1800, declared: "money and iron are the things required to command peace". The Corsican conqueror did not, like his minister, only think of the value of iron as a means for promoting culture in times of peace; he evidently intended to characterize its sinister significance for warlike purposes in the sense of the old Roman "igne ferroque".

Such being the general opinion at the beginning of the century, it became fully established during its further progress and termination. Engineering and above all the material indispensable to engineering work, viz. iron, have supplied to the nineteenth century the material foundation for its progress and thereby ineffaceably impressed it with their stamp. The universal exhibitions held during the second half of the century, being unknown before that time, revealed to the public these wonders of engineering. The first World's Fair, held in London in 1851, proved to be an event of the greatest importance to the iron industry of all countries. It had a particularly favourable effect on the German power of competition by strengthening the self reliance of those among the exhibitors, who won prices and distinctions, and above all by making it clear beyond doubt, "that the much admired English industry in technical respects was not so greatly in advance as to be unapproachable by other countries"[1]). It may be confidently expected that the German industry will continue to honourably hold its own with foreign countries, when the last great exhibition of the century at Paris will bear testimony to the universal progress made in all branches of engineering, originated as they are by the great inventions of the century and developed by constant and methodical exertion.

Technical science too, raising its commanding voice more forcibly than ever before, will be represented at Paris in all its branches and with all special features characterizing it. Against prejudices, disdain and supercilious ignorance of its substance and import it has fought strenuously and without intermission, relying on its own inherent force and qualities. And now, the century drawing to a close, the claim of its being put on a level with the more privileged branches of science, as taught from times of old by the universities, a claim acknowledged long ago by most other countries, will, it is hoped, no longer be denied by Germany alone. "Acknowledging the position engineering has won for itself at the end of our century", the German emperor, ever clear sighted, a short time ago has conferred seats and votes in the Prussian Upper House on the three large Prussian technical colleges of Berlin, Hanover and Aix-la-Chapelle. With barely concealed discontent most of the universities are still watching the growing success of engineering science, and many of their most esteemed representatives have disputed by word and writing the right of equality claimed by their technical sister institutions. As to the final issue of this contest, only those people can be in doubt, who purposely close their eyes to the signs of the day, or who are wanting in knowledge and discernment necessary for judging them. Of the greatest significance in this connection was the centenary of the Royal technical college of Berlin, celebrated in a brilliant manner in October last, when by the decision of the emperor the well deserved but hotly disputed right of graduating doctors of engineering was conferred on the German technical colleges.

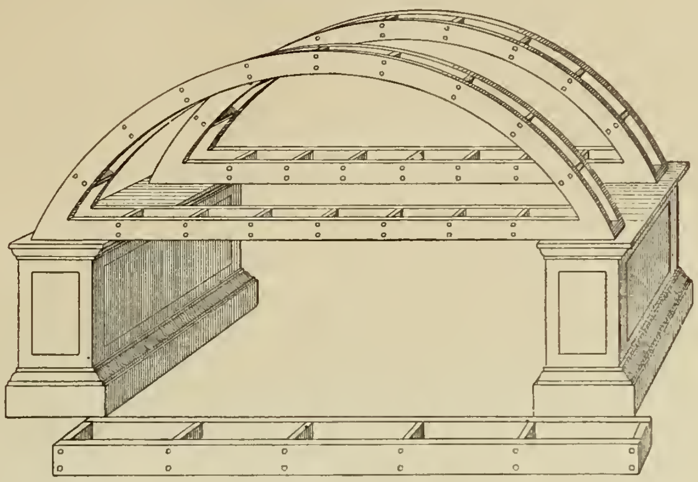
Looking back at the economical development of the nineteenth century, we recognize, in how much quicker and thoroughgoing a manner innovations and improvements following new ideas and inventions, are being adopted to-day than at the beginning of the century. Phenomenal events follow each other with startling rapidity, comparable in their action to modern wars, which putting forth their ravaging forces gain unheard of successes with lightning speed. Simultaneously the threads of trade, crossing lands and seas, are drawing closer together all parts of the globe; its pulse are beatings quicker and stronger than ever. Blessed is that people, which rightly interpreting the signs of the time, adapts its own commercial life to that of the whole world. It alone will be able, thoroughly prepared, to await the unavoidable changes and transformations, which the coming century is sure to bring forth.

2. THE FIRST IRON BRIDGES. In ancient times iron was mainly prized on account of its manifold application in warfare. In agriculture and trade generally its use was greatly limited, and in architecture it was scarcely ever met with. This state of things changed very little in the course of centuries. Even when architecture flourished during the Middle Ages, people did not know how to make use of iron except for special purposes, like mountings for doors and windows, for dowelling stone masonry, strengthening timber joints and timber structures generally, finally for tying arches and cupolas. It was only at the beginning of the nineteenth century that timber and stone, which up to that time had ruled supreme, were at last replaced by iron in all branches of construction, and for this reason alone the designation of the nineteenth century as the "iron century" appears justified.

In *bridgebuilding* too the employment of iron, up to the close of the eighteenth century, did not advance much further than in other branches of construction. Looking at the admirable remains left of ancient bridgebuilding, this might appear strange at first sight. At any rate, the question arises, why the architects and engineers of classic antiquity, whose marvellous abilities are impressing every-

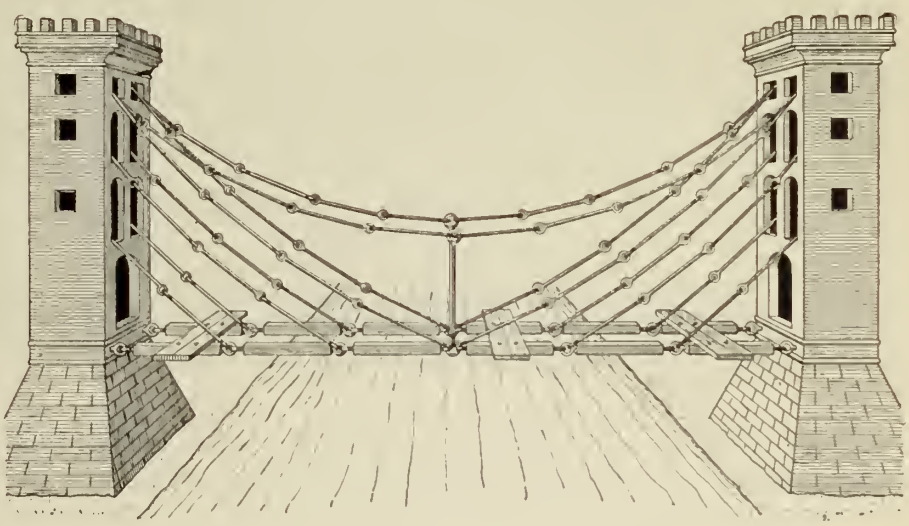
body, who contemplates their works, did not make use of iron as a material for the gigantic structures they left behind them. The answer is readily supplied by the history of iron itself: At that time iron and steel were far too costly compared to timber and stone, to be applied

Fig. 1. Archbridge of Faustus Verantius. 1617.



to other purposes than objects indispensable to everyday life, like arms and tools. Far distant from the great traffic roads, up lonely wooded valleys, the places were to be found, where iron was won in small quantities only, and *immediately from the ore*, a lengthy and troublesome process. Moreover, there was a lack of suitable tools for

Fig. 2. Suspension bridge of Faustus Verantius. 1617.



forcing the metal into the forms and connections desired, while in case of the competing materials timber and stone these difficulties practically did not exist.

Cast iron was unknown during the Old Ages. Even after the *indirect production of iron* as well as *iron founding* had been invented, the state of things described above did not become much altered. At first cast iron was applied exclusively to the purposes of war, by making guns of it. The oldest cast iron guns in existence are to be found at the Germanic Museum at Nuremberg, while in the arsenal at Murten there is a gun dating from the battle against Charles the Bold, in 1476. Nobody yet appeared to have thought of making use of cast iron for building operations.

At the beginning of the sixteenth century the idea of casting bridges, roofs and floors entirely of bell-metal, is first met with in a writing by the Venetian engineer, *Faustus Verantius* of Dalmatia, dating from 1617[2]). Verantius gives a sketch of an arched bridge (see fig. 1), which he describes as follows: "This bridge, straight or arched, shall be made entirely of bell-metal. People may say, that a great deal of bell-metal would be required and therefore the expense might rise high; to that my answer is, that the cost will be much less than that of a bridge built of stone. Further, somebody might ask: How can so large a structure be made and cast at all? That question you had better ask the gunmakers. If they cannot tell you, then return to me. In the same manner and with much less expense the roofs and floors of large buildings and churches could be made."

According to this Verantius does not appear to regard cast iron as a material suitable for his purposes, because no doubt he was aware that nearly 200 years before his time guns were already being manufactured not only of bronze but of cast iron as well. On the other hand, his writing further on contains a drawing of a *suspension bridge* (see fig. 2), with its horizontal platform suspended on each side from tower-like piers on shore by means of four rows of wrought iron chains. He describes the bridge as follows: "We call this bridge an iron one, because it is suspended from two towers, built up on both sides of the water, by many iron chains. The towers, however, will be provided with gates, so that travellers can be admitted or locked out at pleasure."

We have no information, whether Verantius has any-

where carried out his ideas and designs, nor do we know what share in them may possibly be due to his predecessors, above all to Leonardo da Vinci (1452—1519), the great artist, engineer and philosopher, who took a leading part in all branches of art and science known at his time, including the building of war- and siege-bridges[2]). At any rate, Verantius' design of an iron chain bridge shows a much more rational construction than the *old Chinese bridges* of the same kind, dating from the sixteenth century. In these instances the road was indeed supported by extended iron chains, but being fixed immediately on top of them, formed quite as difficult and perilous a passage both for foot passengers and horsemen, as those rough and primitive ropeways made of vegetable fibre or creepers, which aborigines are making use of for crossing water-courses.

The reason why these first ideas of building iron bridges, as well as the similar designs of a few French engineers of the eighteenth century, were never carried out, will be easily understood. Suitable tools and plant for the manipulation of *malleable iron* were still wanting, and the competition of timber and stone was consequently overpowering. During the Middle Ages the hammer was the only smith's tool in use and even at the close of the eighteenth, on the threshold of the nineteenth century, the production of wrought iron forgings weighing more than 200 kilos (4 cwt.) was of rare occurrence[3]). An immense advance was, therefore, represented by the introduction of steam power and of coked coal to the working of blast furnaces, which alone made possible the application of *cast iron* to constructive purposes. The merit of taking the lead in this matter is due to Smeaton, the English engineer. In a letter dating from 1782 he says: "When 27 years ago for the first time I made use of cast iron for certain purposes, everybody was asking, how can brittle cast iron resist, where the strongest timber will not stand? The castings referred to are still doing duty to-day, their use has since spread from the North of England to all parts, and I have never yet heard of any fracture." Steam boilers, rolling frames, even water wheels were manufactured of cast iron, and Smeaton made use of it at his mills and at the far famed lighthouse of Eddystone. At Coalbrookdale the first serviceable rail was cast for the coal tramways belonging to the works, in 1767, and three years later the same works produced the *first real iron bridge ever built*, viz. the cast iron bridge crossing the Severn in a span of about 31 metres (102 feet), erected in 1776 to 1779. On the eminent designer and builder of this bridge, *Abraham Darby*, in 1788 the gold medal of the English Society of Arts was bestowed, whose collections still contain a model of the bridge. In addition to this, however, the bridge itself (see fig. 3) is still standing safe and sound at the present moment, and carries the loads passing over it from day to day with *perfect safety*. In its immediate neighbourhood a flourishing town has grown up, rejoicing in the name of "Iron Bridge"[4]). After its model many arch bridges were cast in England and even shipped to America during the last twenty years of the eighteenth century. In Germany a similar bridge was cast at the Royal Ironworks of Malapane as far back as 1794, and erected to serve as a roadbridge over the Striegauer Wasser near Laasan in Lower Silesia. This was the first iron bridge ever built on the Continent of Europe, and it still exists in good condition, as represented in fig. 4.

Fig. 3. Bridge over the Severn at Coalbrookdale. 1779.

Notwithstanding the remarkable success attending the

use of cast iron, as soon as some experience had been gained with it, for buildings generally and bridges in particular, within a short time, in fact already during the second quarter of the present century, it had to give way again to malleable iron, after the combined inventions of puddling or fining within the furnace and of grooved rollers had proved successful, and after a considerable goods and passenger traffic had grown up on locomotive railways beside that on roads and on coalmine-tramways already in existence. At this point cast iron, mainly on account of its deficient resistance against bending, had reached its limit as a constructive material, and puddled iron or *wrought iron,* as we call it to-day, began its upward career. Timber and stone, however, for some dozens of years continued to compete strongly with iron, particularly on the Continent of Europe, where people apparently could do nothing but imitate English methods. In consequence, however, of political, economical and social difficulties English inventions concerning iron industries took root only very slowly and tardily on continental soil. They came to Germany only by way of Belgium and France. Many German ironworks continued to adhere for a long time to the open-hearth process worked by charcoal, and even in places where the puddling process had already been adopted, technical imperfections and difficulties in rolling the first sections, notably of angle and tee irons, etc., became the reason, why sufficient quantities of rolled iron could not be produced. Thus it was as late as the middle of the fourties, that the first iron bridges were erected for railway traffic in Central Europe, while in England a great many of them had already been built twenty years before. Of the 63 bridges on the Liverpool and Manchester line, for instance, built in 1825—30, the majority was constructed of iron, while the oldest German and Austrian railways began by building their bridges exclusively of timber and stone.

Fig. 4. Bridge over the Striegauer Wasser at Laasan. 1796.

3. THE MATERIAL OF IRON BRIDGES. During the period of transition just described, concurring with the first half of the century, conflicting opinions naturally prevailed as to the value of cast iron compared to wrought iron or of iron compared to stone and timber. This gave occasion to many practical engineers as well as theorists of making comparative experiments concerning the resistive qualities of building materials, in order to obtain reliable data for judging the points in dispute. Burg reports in the Annuals of the Imp. Royal Polytechnic Institute at Vienna (1814—39) about the older experiments of this kind made by *Barlow. Telford, Rennie, Prony, Rondelet, Tredgold, Bevan, Dulean, Dufour, Lagerhjelm* and others. To these may be added the wire tests of the Frenchmen *Dufour* and *Seguin*, begun in 1814 for the benefit of suspension bridges, followed in 1834 by the first wire tests of long duration by *Vicat* and the particularly prominent experiments of the Englishman *Eaton Hodgkinson* in 1831 and the German *Brix* in 1837. These older investigations were brought to a close by the well-known experiments jointly undertaken by *Stephenson*, the engineer, *Fairbairn*, the ironmaster, and *Hodgkinson*, the theorist, on the occasion of the building of the Britannia Bridge in 1840 to 46[5]).

The final results of all these tests generally led the way to a better knowledge of the behaviour of building materials under varying conditions of load, at the same time proving beyond doubt the striking superiority of wrought iron to cast iron. They especially furnished figured values for the

resistance against *tensile, compressive* and *bending stresses,* as well as for the *modulus of elasticity* and the *limit of elasticity* of constructive materials, supplying by this means the basis for a reliable calculation of the sections required according to well-known methods, to be treated in the following chapters.

In accordance with the results of these tests wrought iron, on account of its tenacity and its almost uniform resistance against tensile and compressive stresses, proved to be the most reliable material for important railway structures of all kinds, permanent way as well as bridges, which are to resist not only the impact produced by live loads, but in many cases heavy strains changing between tension and compression. Thus about the middle of the century the predominance of wrought iron as a building material was practically assured. In the meantime the incessant reciprocal action between railways and iron urged forward further facilities for bulk production as well as the attainment of a *higher standard of resistance* in the new material. The result was at first the substitution of *steel* for iron in many branches of engineering, particularly of *puddled steel*, because *open-hearth steel* did not allow of production in bulk, and *crucible steel*, whilst being admirably suited for gunbarrels and similar large castings, on account of its brittleness was scarcely applicable to the manufacture of braced structures of any kind; it was at the first World's Fair in London, when Krupp first demonstrated how to make crucible steel in large quantities. Thus puddled steel alone, produced in the reverberatory furnace since 1835, came into general use, more particularly for heavy parts like rails, tires etc. For constructive purposes, however, above all in bridgebuilding, open-hearth and puddled steel have been used only in a very few isolated cases, two of which have become better known: The Karl-suspension bridge over the Danube Canal at Vienna, built by *von Mitis* in 1828 with links made of open-hearth steel, which is *the first known application of weld steel to bridge construction,* and the Göta-Elf-Bridge near Trollhättan, with a span of 42 metres (138 feet), designed by *Adelsköld* and finished in 1866, with girders of the fishbelly type made of puddled steel.

For the reasons stated above the exertions of metallurgists were continually directed towards the production of steel in a *liquid state—ingot steel*—and in bulk, without the necessity of using crucible or hearth. This result was first accomplished in 1855 by the late *Henry Bessemer;* and scarcely had the first success crowned Bessemer's great invention, when the French ironworks owned by *Martin* at Sireuil succeeded in obtaining ingot steel in a reverberatory furnace, by the application of gas firing on the "regenerative" system invented by Frederick Siemens. These inventions subsequently became the real foundation of our present system of steel production, by introducing the *converter,* lined with *acid* fireproof material, and the similarly lined *furnace.*

These two new processes may be said to have entirely revolutionised the metallurgy of the world, so much so indeed, that even the old designations of iron and steel have practically become obsolete, and an international commission of eminent metallurgists, assembled at Philadelphia in 1876 on the occasion of the World's Fair, had to invent new names in order to prevent confusion. Following its decision, the material, if obtained in a doughy form, according to its degree of hardness is to be called *weld iron* or *weld steel;* if produced in a liquid state, *ingot iron* or *ingot steel.*

The first instance of the application of ingot steel to constructive purposes is found in the use of *Bessemer steel* for shipbuilding in England in 1860—61[6]). France and America followed during the years 1861 to 64 by making men-of-war's boilers and railway locomotives of the same material. Almost at the same time it was tried to utilise Bessemer steel for the purposes of *bridgebuilding.* The first occasion of this appears to have been, when three road-bridges were built in 1862 by the Dutch local boards of Bunde, Elsloo and Bergen op Zoom. According to documents supplied to the writer by Professor *Krohn,* these bridges consisted of braced girders of from 30 to 37 metres (98 to 121 feet) span. Shortly after (in 1863—64) the Board of the Dutch State Railways introduced Bessemer steel into certain parts of bridges on its system, the first case being that of the Yssel Bridge on the Arnheim—Leuwarden line, built in 1863—64[7]).

Up to the eighties the cases, where Bessemer steel was used in bridgebuilding, were few and far between. The material supplied was of too hard and irregular a texture to be easily worked, and the lack of experience in manipulating it made matters worse. Finally the unfavourable results obtained with Bessemer metal in case of several large bridges built by the Dutch State Railways caused a pronounced distrust against the use of ingot steel generally, which gradually took possession of wide engineering circles throughout Europe. No wonder that *Martin metal* as well had to suffer from the consequences of this, though it had been applied already in shipbuilding yards belonging to the French navy, where in 1874 the first man-of-war was built with a hull made entirely of Martin steel. On the other hand, up to 1880 scarcely anybody had ventured to make a trial of it in a bridgebuilding yard or in other branches of constructive engineering. As far as known, it was Mr. Frühling, at that time a city engineer at Königsberg, now a professor at Dresden, who first tried to use Martin steel in bridge construction in 1880. Soon after, between 1883 and 1890, the great stucture of the Forth Bridge was built entirely of Martin metal.

The next powerful impulse towards the successful application of mild steel to engineering structures of all kinds was given by *Thomas'* far famed invention of dephosphorising iron within the Bessemer converter in 1878, which a few years after (in 1882) was also applied to the Martin furnace. Both converter and furnace were lined with *basic* material.

From that moment the material produced consisted of two kinds differing in fundamental qualities: The *acid* steel as produced by the old Bessemer or Martin process and the *basic* steel, obtained in the converter or furnace by means of dephosphorisation. The difference between them consists principally in the degree of *hardness* obtained, the basic variety comprising the *milder* kinds of steel, while acid metal as a rule is used in its *harder* form only. There can be no doubt that of the two basic steel

generally speaking has the advantage of greater purity, uniformity and tenacity, qualities which have made it extremely valuable as a building material for universal use.

While, therefore, the endeavour to obtain steel in a liquid state, by developing Bessemer's, Martin's and Thomas' great inventions, has in the course of time been successful in producing a material resembling *steel* in its general character, it is an important fact that in other respects its qualities are those of a tenacious kind of *wrought iron,* and it may be said that this result was obtained without at first intending it and without at once realising its importance. The metallurgists of most countries continue to call the new material *"steel"*, while in Germany it is named *"Flusseisen"*, which corresponds to the *"acier doux"* of the French and the *"soft steel"* or *"mild steel"* of the English or Americans. Its scientific names are *"fer fondu"* in French and *"ingot iron"* in English.

In a paper read at the Chicago Exhibition the writer has supplied two tables of remarkable bridges of all countries, dating from the last twenty years, the superstructures of which are made entirely of mild steel. From these tables it will be seen that the first bridge made of basic steel was a railway pin-bridge for the Deli-Spoorweg Company of Sumatra, built in 1885*). They were followed by several Austrian and French bridges, constructed in 1886 and 87.

At first Martin steel for constructive purposes was preferred to Thomas steel, a fact easily explained by the greater experience gained in the Martin process, which, dating as it does from 1865, is thirteen years older than the invention of dephosphorising iron within the Bessemer converter. Thus the acid Martin metal had succeeded in gaining a large field of application, before the Thomas process had conquered its initial difficulties and found time to fight its own way. As late as the eighties Thomas steel was not generally considered equal in quality to Martin metal, and if at present professional opinion in Germany has turned round in favour of the former, this change is due in a great measure to the impression produced by the extensive series of comparative experiments, conducted in 1889—93 under the direction of the writer, in connection with the building of the great Vistula bridges near Dirschau, Marienburg and Fordon[8]).

At that time many enquiries about this matter were directed by German and foreign building departments to the Royal Railway Board at Bromberg as well as to the author; and there can be no doubt that a great impetus was given to the more general adoption of mild steel for structures, principally bridges, by the success attending the use of basic steel on that occasion. Professor *Krohn*, general manager of an important bridge company, has confirmed this in a paper read at Düsseldorf, in which he says: "By means of these bridges and the extensive tests preceding their construction the introduction of mild steel into German bridge-building became an assured fact, and to-day, when barely five years have passed since that first attempt, mild steel in its application to all kinds of iron structures has entirely thrown into the background the older material of wrought iron, which for more than half a century had ruled the market"[9]).

*) By the Harkort Company at Duisburg.

The world's production of mild steel during the last year of the century amounts to roughly *20 million tons,* about 10,5 millions of this being *basic,* 9,5 millions *acid* metal. The 10,5 million tons of basic steel are produced by the following countries:

	Millions of tons Thomas	Martin	Total
1) Germany (including Luxemburg) .	3,80	1,60	5,40
2) United States of America . . .	—	—	1,80
3) France	—	—	0,90
4) Austria-Hungary	0,25	0,60	0,85
5) Great Britain	0,55	0,25	0,80
6) Other countries	—	—	0,75
			10,50

These figures prove the leading part Germany has taken in the manufacture of basic mild steel. Its production is at present *three times* that of the United States, that of all other countries being comparatively insignificant. On the other hand, Great Britain as well as America continue to turn out acid steel in large quantities, their combined output in 1899 being a little over 8 million tons, i. e. about 40 per cent of the world's entire production of mild steel.

Looking back at the development of constructive materials during the century, the same thought presents itself in a more forcible form, which was already given expression to before (see page 2). The changes come quicker and their action goes deeper, the more we approach the end of the century. Our time is living fast, and the words of the great German poet: „Das Alte stürzt, es ändert sich die Zeit“, are proving even truer to-day, than they did during his own lifetime. With the advent of the iron roads, on which trains rush along and electric messages are flashed to the utmost corners of the world, wrought iron was raised from obscurity; but after a short time of rapid rise it proved unable to keep pace with the wings of the flying wheel and fell back, only to give way to its more robust and tenacious fellow, mild steel. For many thousands of years the iron obtained immediately from the ore prevailed, then the metal produced on the hearth took the lead for 400 years. Compared to this, the eighty years, during which wrought iron ruled supreme, and the short period, since it was superseded in its turn, lapse into insignificance. Who will assert, how long mild steel in its present form will keep its place? Already aluminium and nickel are being added to it for different purposes, and no doubt further surprises are awaiting us in the course of the coming century.

II.

The history of girder systems and of the theory of bridges.

4. GENERAL SURVEY. As practice always preceded science, thus the invention of constructive systems preceded their theory. At all times there was no lack of men born to be inventors, men of great imaginative and intellectual powers, who withont any theoretical knowledge, by closely observing physical processes, became capable of creating mechanical contrivances, which in themselves contained the promise of higher development. Centuries, before theory as we know it to-day was even thought of, there were in existence tools, apparatus and structures of all kinds, bridges not excepted. But it required a long continued accumulation and adjustment of experience, before *practice* and *theory* of bridge construction could be separated and raised by the light of science, until at last by the reunion of both the highest aim of our art was accomplished.

The oldest kinds of girders used to span an opening consisted of simple stone or timber beams. Soon people learned how to increase the span by means of corbels and brackets as well as by adding timber or stone supports and piers. At the same time stone arches and rope bridges, as described in the opening chapter, came into use. The *triangular strut-frame*, consisting of stone flags or wood-beams, diagonally put together, is of very great age[10]). By putting inclined supports underneath a beam, the *trapezium strut-frame* was formed.

There can be no doubt that all these oldest bridge girders were *full-webbed* ones. The *braced girder* was developed only some centuries later in imitation of roof structures. It is of interest to note in this connection, how the idea of *the true triangular frame of bars* can be traced to old roof principals as well as to the bracing system of certain timber bridges, built during the early Middle Ages, how later on this constructive form gradually became obscured and was thrown into the background, until at last, towards the beginning of the nineteenth century, it was taken up again by American engineers and became the principal model for the most important types of braced iron girders in use at present.

The perfection of braced girders for iron bridges is entirely the work of the nineteenth ecntury. It may, in fact, be asserted that the art of building iron bridges is practically a creation of last century's engineering, though of course the foundation of modern constructive systems is to be found in the timber structures of the past, and the first attempts and beginnings of iron bridge-building reach back as far as the seventeenth century (see Introduction).

The same may be said of the *theory of bridges*, which has been really perfected only since the adoption of braced girders during the nineteenth century. *Stevin* (1548—1620) and *Galilei* (1564—1642) supplied the first elements of general statics and of the theory of elasticity, and before the beginning of the nineteenth century these two branches of technical science were then brought to a certain conclusion, *Navier* (1785—1836) for the first time making use of them in a comprehensive manner in his work on "constructive mechanics" for the calculation of strains in all kinds of structures. Navier is, therefore, rightly considered to be the founder of the science of *constructive statics*.

During the first half of the nineteenth century it was principally the *theory of elasticity*, which was being perfected at first, and of that mainly the part relating to bending strains. The essential qualities of braced girders were not yet fully unterstood at that period, and up to the time, when Culmann and Schwedler in 1851 published their fundamental works on this subject, they were calculated in an imperfect manner from the bending moments, the bracing bars being entirely neglected and considered merely as a necessary addition to prevent the flanges getting displaced.

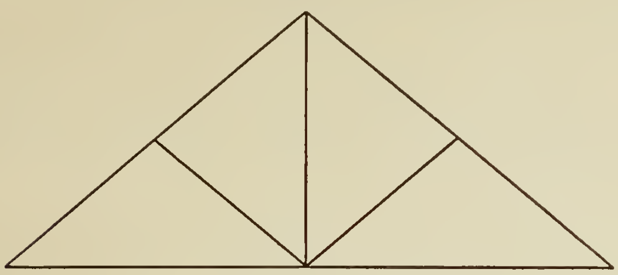
During the second half of the nineteenth century the science of constructive statics was more and more extended in depth and breadth, and led by *graphic statics*, which had been created by *Culmann*, perfected by *Maxwell, Mohr, Cremona* and others, the influence of theory became visibly strengthened. Graphics opened up new fields of knowledge; the theorems of equilibrium and the methods of calculating the strains of bar systems in the plane and in space were brought to their simplest and most perfect form, the difference in the treatment of statically determined and undetermined systems coming out into sharper relief at the same time. After *Mohr* had taught us to draw the

elastic line as a funicular curve and to apply the principle of virtual movements to the determination of formations in braced girders, after *Castigliano* and *Fränkel* for the first time had made use of the theorem of the *"minimum of work in deforming frames"*, constructive statics, as it then stood, already furnished the general fundamental principle, by means of which even statically undetermined structures became accessible to graphical and analytical treatment.

Thus during the second half of the century theory supplied the means of raising in intrinsic value and remodelling by the light of science the older systems, created as they were without much theoretical knowledge.

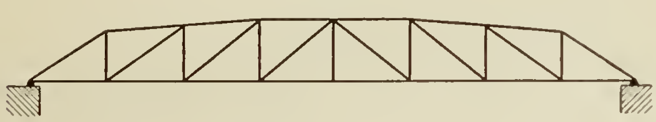
5. TIMBER CONSTRUCTION AS A MODEL FOR BAR SYSTEMS. Braced girders have been developed from

Fig. 5. Roman roof principal.



timber roof trusses. The principle underlying their construction was discovered, as soon as poeple had learned to provide for the thrust of a triangular or trapezium strut-

Fig. 6. German braced girder bridge of the 16th century.

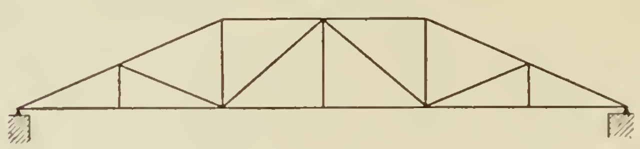


frame by fixing to it a lower horizontal tie-beam. The want of a structure of this kind became apparent in roofing houses, where it proved necessary to protect the walls against the thrust of the rafters. The ancient simple triangular roof was the true solution of this problem.

Very soon after the central king-post of the triangular roof made its appearance, and during a further stage of development the lower braces starting from its base were added in the case of larger spans (see fig. 5). Principals of this kind are already found in Roman timber roofs, they represented truss-frames in the form of true triangular bar systems. The same form of construction according to *Durm* is also met with in old Egyptian buildings[10]).

It may be assumed that following the model of roof structures, triangular and trapezium truss-frames as well as strut-frames have been used for timber bridges at a very early period. We are not, however, in possession of any special information about this. It is said that Trajan's Danube bridge was formed of arched timber frames of a clear span of 36 metres (118 feet), though this is not sufficiently clear from the well known reliefs found on Trajan's column. There is also in existence a Roman medal, representing a timber arch of fair size with a platform suspended from it, probably the old bridge at Mayence[11]). At any rate there can be no doubt that at the time of *Palladio* both kinds of frames had already been brought to comparatively great perfection in bridgebuilding. In Palladio's four books of architecture, published in 1570, a drawing of two lattice girders is to be found, which already show the true triangular system of bars. The type represented in fig. 6 according to his statement has been met with, when travelling in Germany, by Picheroni de Mirandola, no similar example being found in Italy. In fig. 7 the girders of the Cismone bridge with a span of 35 metres (114 feet) are shown, which have probably been designed by Palladio himself.

Fig. 7. Palladio's Cismone Bridge.



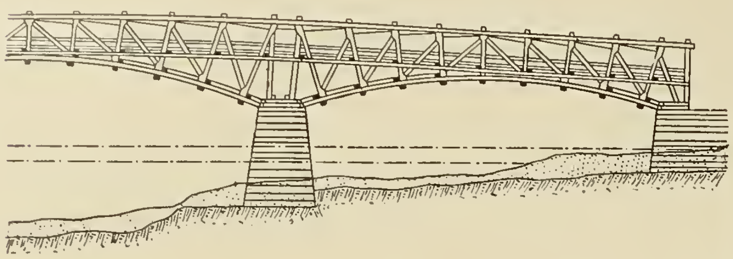
Though in the case of these two girders the principle of the triangular bar frame can be clearly discerned, no imitation of them worth noticing can be traced either during the seventeenth or the eighteenth century. Probably the reason for this is to be found partly in the inability on the part of the designers of making the node connections of the timber bars strong enough to resist permanently the varying action of the forces. On the other hand, no way was yet known at that time of determining the stresses in those bars by calculation, for the scientific truths discovered by a few eminent scholars like Stevin and Galilei, only spread very slowly and did not penetrate very far. Is is only during the nineteenth century that they have become common property. If we finally reflect that timber can under no circumstances be considered a very suitable material for lattice girders of the kind described above, the bracing bars of which have to resist alternative tensile and compressive stresses, it will be easily understood, why even during the eighteenth century Palladio's triangular frames were entirly dispensed with.

Nobody yet clearly realised the value of simple triangular connections. Everywhere, in architecture as well as in bridgebuilding, complicated systems of trussed and strutted frames were preferred, and with the growing span of structures the number of stays and ties tended greatly to increase. In cases where braced girders could not be dispensed with, their flanges were connected by means of *St. Andrew's crosses*, in order to prevent displacements.

For the purpose of doing away with the horizontal thrust of the arched strut-frame on its abutment, the girder of the *bow-string type* was then introduced. North America in this instance went ahead of Europe, where merely some Swiss structures and those designed by Wiebeking were of any interest. *Culmann's* well known Travelling Report of 1851[12]) and *Cooper's* Notes[13]) (of 1889), supply much useful information about American timber bridge systems, which had been steadly perfected with a good deal of judgement and insight into the action of forces, though without much calculation. Among these there are two very remarkable lattice bridges designed by *Timothy Palmer:* The Essex-Merrimack Bridge, built in Massachusetts in 1792, a strongly strutted timber frame bridge,

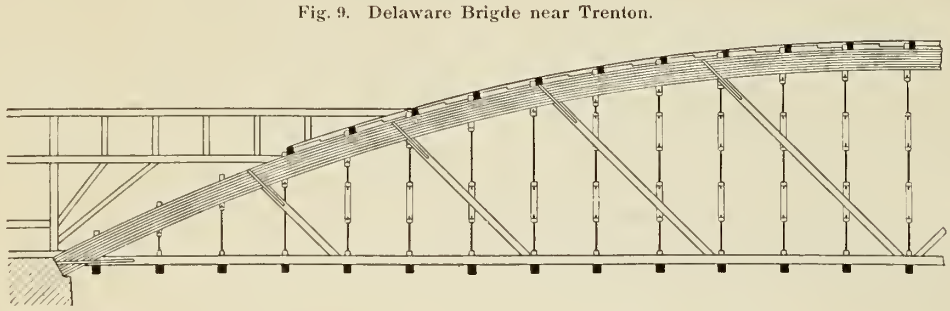
and the Schuylkill Bridge in Philadelphia, built in 1804 to 1806, an arched lattice bridge with a straight top flange and triangular bracing (see fig. 8). Particular renown has been won by *Burr's* designs, above all by his Delaware Bridge, built near Trenton in 1804—6 with spans up to 62 metres (203 feet), consisting of arched girders with the

Fig. 8. Schuylkill Bridge at Philadelphia.



horizontal thrust partly provided for (see fig. 9), further by his system of an arch stiffened by means of a lattice girder (see fig. 10). Even the semi-parabolic type of girder, so much in evidence at present, is to be met with among American timber bridges dating from the thirties. Real timber arches, like the well known Cascade Bridge of the Erie Railroad, built in 1848 with a span of 53 metres

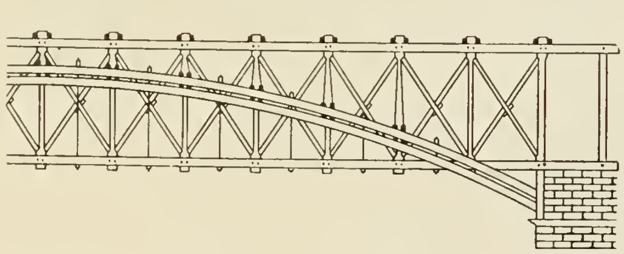
Fig. 9. Delaware Brigde near Trenton.



(174 feet), have found little imitation. In the course of the development of timber bridges girders had already gained the upper hand, after *Town* had in 1829 introduced the lattice girder with parallel flanges, and his successors, *Long* (in 1830) and *Howe* (in 1840) provided the parallel lattice girder with *counter struts.*

By putting counter struts into each panel of a timber girder, it was intended to do away with the change between tensile and compressive strains in the bracing. It is due to Howe, however, that this purpose was at last accomplished successfully by adopting iron

Fig. 10. Bridge over the Connecticut at Bellow Falls. 53.3 metres (175 feet).



tie-rods in place of Long's wooden keys. By means of these tie-rods it became possible to impart to each diagonal strut an artificial compressive strain of sufficient intensity to prevent its being strained in tension either by the dead load alone, or by any live loads passing over the bridge.

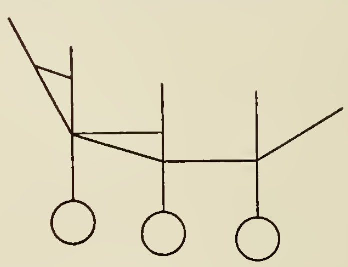
According to Cooper[13]) neither Long nor Howe were able to make any accurate calculation of their systems. How to calculate a lattice girder with counter struts, was, indeed, shown first by Culmann in 1852 by the example of the iron Wye Bridge at Chepstow.

Similarly the first *braced roof principals of timber and iron,* as adopted during the forties or fifties (probably at first in England), as well as the so-called French roof trusses, proposed at the same time by *Wiegmann*[14]), a professor of Düsseldorf, and *Polonceau,* the French engineer, have never been accurately calculated at the time. As pointed out by *Long*[15]), the German Wiegmann appears to have been the first to clearly grasp the principle of the stiff frame, for he intended "to form a plane out of triangles in such a way, as to make impossible any deformation within itself without destroying them". Wiegmann already tries to accomplish the calculation of a so-called trussed girder by means of applying the theorem of equilibrium *round each node.* This, indeed, is the characteristic point of the stiff frame principle, which need not take into account bending stresses at all.

6. FIRST HISTORY OF STATICS AND OF THE THEORY OF ELASTICITY UP TO NAVIER.

Statics is the oldest branch of mechanics. As far back as Archimedes' time people knew how to determine the abutment pressures of a loaded beam by means of the law of leverage. On the other hand, the method of resolving and composing forces, acting in one point, was only indicated by *Stevin* (1548—1620). From the condition of equilibrium in the inclined plane he deduced the principle of the funicular curve or funicular machine, as it was then called[16]). He was able to represent the three forces acting in each node of the polygon in proportion to their size by the sides of a triangle (see fig. 11). This was the real beginning of graphics. In the

Fig. 11. Stevin's funicular and force polygon.



course of his further investigations into the equilibrium of pulleys and systems of pulleys he, moreover, discovered the validity of the principle of virtual velocities, the general import of which, however, was only recognised by John Bernouilli in 1717. Even before this, in 1687, the theorem of the decomposition of forces had been given its most general analytical form by *Varignon.* It may be worth remarking that in 1747 *Maupertius* published the principle of the *minimum effect,* called by him the "principe

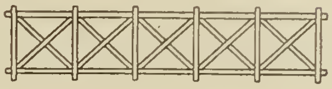
de la moindre quantité d'action", because this theorem comprises that of the minimum work of deformation, applied first by *Castigliano* and *Fränkel*. These theorems, however, have only been used for the calculation of braced systems during the second half of the nineteenth century. Up to that time the theory of elasticity, particularly that part of it relating to bending strains, had to serve as a substitute.

Since Galilei's time a large number of investigators during the seventeenth and eighteenth centuries tried to solve the problems of bending stresses theoretically as well as practically by making experiments. *Hooke* and *Mariotte* discovered the so-called *theorem of elasticity*. *Parent, Jacob Bernouilli, Euler, Lagrange* and *Coulomb* extended the theory of the elastic line. *Coulomb* (1736 to 1806) published the first scientific work, founded on correct assumptions, on the simplest cases of the theory of elasticity and resistance[17]). He assumes extended and compressed fibres within a body subjected to bending stresses and determines the position of the neutral axis by the condition that the sum of the stresses in the extended fibres must be equal to that in the compressed fibres. He finds that in the case of symmetrical sections the neutral axis goes through the centre line between top and bottom fibres, and discovers besides, that in case of fracture its position may become altered. Coulomb, moreover, was the first to recognize that forces are being developed in a section, which act in the plane of the section itself, because otherwise no equilibrium with the external force is possible. He was not yet able to determine the size of these forces, the *shearing strains*, but he is aware that their sum equals the external force, so that they cannot like tensile and compressive strains be dependent on the length of the body. He, therefore, concludes that the calculation of the breaking strain, as given by himself, can only be correct in case these shearing strains have but little influence on the tendency to breaking, or in case the leverage of the load is much greater than the height of the beam.

Navier (1785—1836) continued the researches of his predecessors. It was reserved to him to advance the problem of bending strains by a decisive step. He proved that the neutral axis goes through the centre of gravity, and deduced the well known strain expression: $N = \frac{M\,v}{J}$, in which, as *Persy* first shows in 1834, J represents the moment of inertia of the section. In the preface to the first edition of his celebrated work, published in 1826, Navier points out that of the investigations of his predecessors "mathematicians have made greater use than architects and engineers". He further says: "Most designers determine the dimensions of parts of structures or machines according to the practice prevailing at the time or in imitation of other examples; they rarely take into account the pressure each part is subjected to or the resistance it offers".

In the last chapter of his book[19]) Navier treats the theory of timber and iron structures. Iron bridges, of course, are scarcely mentioned. The general principle, applicable in his opinion to the design of structures of all kinds, consists in "arranging the principal parts in the direction of a straight line, connecting the points of application of the loads to the points of support. In a structure designed in this manner, the loads do not show any tendency of turning the different parts round their end connections. This principle is particularly adapted to structures supported from below". From this it will be easily understood, why Navier in his work almost exclusively discourses on strut-frames with the platform arranged on the top. He gives, it is true, the drawing of two braced parallel-girders (see fig. 12), but he only calculates the bending stresses of the flanges and states that the assumption, on which his calculation is based, is only realised "in case the bars are connected to each other by a series of stays and St. Andrew's crosses or by means of keys and notches. If, on the other hand, one of the bars or both of them are arch-shaped (see fig. 13), a connection by means of simple stays will be sufficient, provided the end connections of the bars are of a kind to prevent their sliding on each other". Navier's opinion on this matter was almost universally shared up to the time, when Culmann's and Schwedler's researches, referred to above, were published.

Fig. 12. Navier's braced girder.



Parallel-girder with let-in crosspieces.

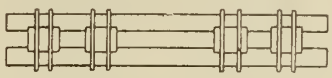
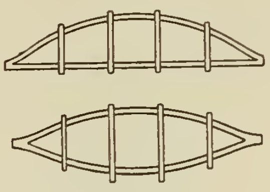


Fig. 13. Navier's arched beams.



7. THE OLDER BRIDGE SYSTEMS OF THE NINETEENTH CENTURY. Generally speaking three principal groups of bridges are distinguished, called according to their manner of support *suspension bridges*, *arch bridges* and *girder bridges*. Their distinctive feature consists in the direction of the abutment pressure under a vertical load. In the case of oblique pressure, the horizontal component of which exerts either a tension or thrust on the pier, the structure is called a suspension bridge or arch respectively. In case of a girder bridge vertical abutment pressures only are present, no lateral action on the piers taking place. The latter remark also refers to tied arches, which in this respect can be classified as girders.

At the beginning of the nineteenth century there were already in existence iron suspension bridges as well as arches of considerable span, whilst girder bridges at first were of minor importance. It was only when railways began to spread far and wide, that girders began to push their way in, because it was considered that suspension bridges as well as most kinds of arches, while being strong enough to carry street traffic, were not sufficiently safe for the demands of railway traffic. The reasons for this were obvious:

Suspension bridges at that period had their main cables made of wire rope or links, from which the road platform was suspended by means of vertical tierods or wire ropes; it is evident that under these circumstances unsymmetrical loads would tend to produce vibrations of considerable magnitude. Suitable arrangements to prevent this, like bracing within the plane of the girder between platform and cable, the latter being very flexible, were lacking. Moreover, the bracing required to counteract the action of wind and other lateral forces, was as a rule wholly inadequate. Navier, who in 1821 travelled to England for the purpose of studying the suspension bridges of that country, in 1824 published his "Mémoire sur les ponts suspendus", which besides some views of very ancient types of truss-frames, contains a description of English suspension bridges of the period, as well as the first sound theory of suspension bridges. Telford's first design of the Menai Roadbridge will also be found in it. From this the interesting fact may be learned that Telford at first intended to put cross bracing for stiffening purposes between the two chains of his suspension cables, as well as between the parapet beams of the platform. The bracing between the chains has, however, been omitted in the real structure, as built in 1818—1826. It was indeed as late as 1836, when the old chain bridge (now removed) over the Weser at Hameln was constructed by *Wendelstadt*, that for the first time triangular stiffening frames were introduced between the two chains, one being vertically above the other, of the suspension member.

Nothing more characteristic of the estimation in which suspension bridges were held at that time, can be found than the result of the competition for the Rhine Bridge at Cologne in 1850. Schwedler's design of a stiffened suspension bridge (see fig. 14) indeed received the first price, but it was not unreservedly recommended for execution, although according to the conditions railway carriages only, *without engines,* were to pass over the bridge[18]). Later on, following American precedents, it has been tried on a single occasion to construct a similarly stiffened suspension bridge for a main line railway in Europe. That event happened in Vienna in 1859, when *Schnirch* built his bridge over the Danube Canal; it did not, however, last longer than 25 years, when it had to be pulled down on account of incipient senile infirmity. The first example of a suspension bridge serving the traffic of a railway trunk line, is that of Röbling's stiffened wire-bridge over the Niagara, opened in 1855. It was materially strengthened on several occasions during the last ten years, but had to be removed and replaced by an iron arch in 1897, because it was not considered sufficiently safe for carrying the heavy railway trains of our time.

As it became evident, in short, that suspension bridges were unsuitable for railway traffic, engineers would have been inclined to try arch bridges in cases, where the local conditions proved favourable, the cast iron Severn Bridge near Coalbrookdale (see fig. 3) having then been successfully finished. Many reasons, however, told against it (see Introduction), above all the deficient strength of cast iron under bending stresses, its doubtful behaviour when exposed to the impact of live loads, finally the increasing competition of wrought iron, growing stronger and stronger with the extension of railways. Besides, the lack of theoretical means for correctly calculating arch structures, has probably added its influence. At any rate, cast iron arches never became very prominent, as far as roadbridges

Fig. 14. Schwedler's design of a stiffened suspension bridge for Cologne. Awarded first prize. 1850.
(Dimensions in metres)

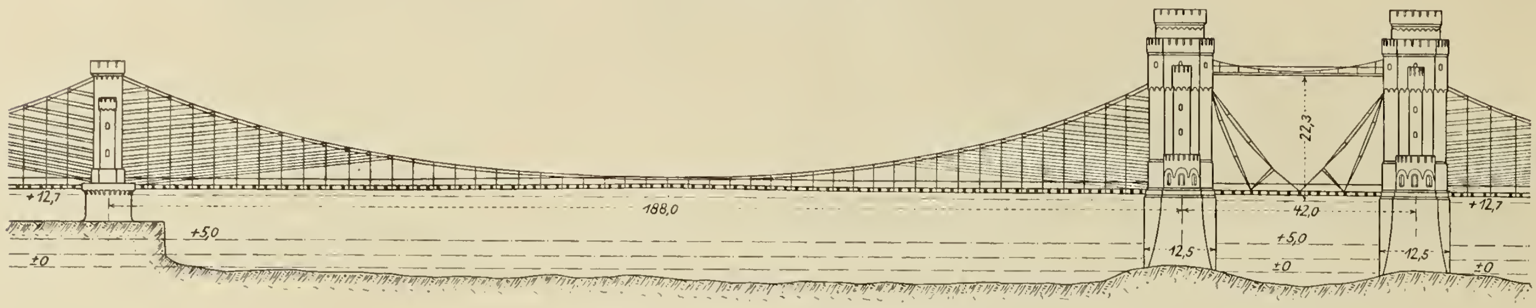
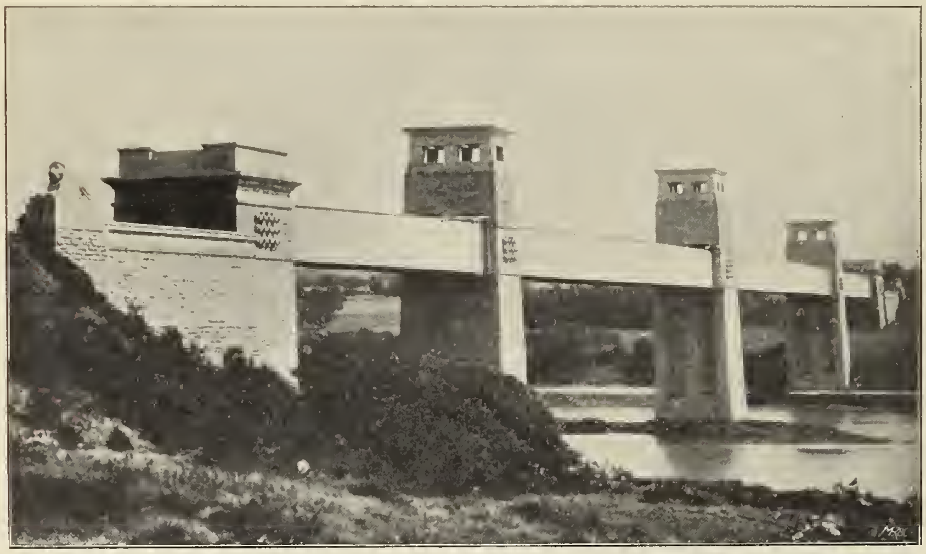


Fig. 15. Britannia Bridge over the Menai Straits between Wales and Anglesea. 1849.



were concerned, and in case of railway bridges were scarcely used at all. On the other hand, the attempt of Bruyère, a Frenchman, to construct a wrought iron arch bridge in 1808, crossing the Crou at St. Denis in a span of 12 metres (39 feet), was imitated only after a lapse of 50 years, during the fifties, when the advance made in theory as well as in the design of girders in the meantime had instigated further progress in the construction of arches as well.

The first iron girder bridges for railways were provided with full-webbed girders. Besides timber and stone, cast iron was the material first used for beams up to about 20 metres (66 feet), followed later on by wrought iron plate girders. Up to the nearly middle of the century the span of much more advantageous it would have been to replace the webplates of the boxgirders by *close lattice bracing* of the kind used for small spans, in imitation of Town's timber lattice bridges, in England as well as (since 1846) in Germany.

The same system of close lattice was, after a good deal of hesitation, adopted in case of the old Dirschau Vistula Bridge on the Berlin—Königsberg line of railway, which has six openings of 131 metres (430 feet) each and was the first Continental girder bridge of large span (see fig. 16). Even then this system did not find favour with a good many of the experts of that period. Above all Culmann and Schwedler, according to statements contained in their works referred to before, regarded the adoption

Fig. 16. Old Vistula Bridge at Dirschau. On the left the new bridge in course of construction (1850 and 1890).

plate girder bridges did not exceed about 70 metres (230 feet). At that time (1846—49) the first large span, with openings of 142 m (466 feet) made its appearance. It was the well-known Britannia Bridge crossing the Menai Straits on the Chester—Holyhead line of railway. When *Robert Stephenson*, the son of George Stephenson, of railway fame, received the order for this magnificent structure, he first submitted designs of a cast iron arch bridge and a wrought iron suspension bridge, these systems being at that time the only ones tried for similar spans. Finally, however, he turned his attention to the girder system and designed a wrought iron *box girder* bridge of a size large enough for a whole railway train to pass through (see fig. 15).

The box girder type with full webs has only found a single imitation, viz. the Victoria Bridge over the St. Lawrence river at Montreal. In Germany it was recognised even during the construction of the bridge, how of this system as a retrograde step, recommending at the same time girders with a more rational system of bracing (compare 9).

8. THE THEORY OF ELASTICITY AFTER NAVIER[19].

On the foundation supplied by Navier the French engineers Cauchy, de Saint-Venant, Bresse and Lamé continued to extend the theorems relating to bending stresses. *Cauchy* in 1827 explained for the first time the general properties of stresses acting on any plane within a body and in the course of his investigations derives the theorem of the *ellipsoid of deformation*: *Lamé* in 1852 puts Cauchy's results into a geometrical form and introduces the *strain ellipsoid* as well as the *principal strains*. *De Saint-Venant* in 1853 deduces the principle of bending strains in its most general form and shows the influence of *shearing strains*, neglected by Navier, as well as the relation between *sliding* and *extension*, at the same

time making use of the theory of the *ellipse of inertia*, originated by *Poinsot*. *Bresse* in 1854 perfects the theory of bending strains by introducing for the first time the *core of a section*.

On the assumptions made and the foundation supplied by these writers even to-day the calculations of elastic structures are chiefly based, though it has been attempted in many cases—among others by *Clebsch, Clausius, Kirchhoff, Pochhammer* and *Weyrauch*—to build up an even more exact theory of elasticity. In a novel manner and with great success *Bach* has tried to base the theory of elasticity and resistance more than before on the results of experiments. His important work "Elasticität und Festigkeit" has already been published in three editions. Bach has certainly taken the right course in correcting the empirical figures contained in the formulae of our present theory of elasticity by means of the results of tests made in the course of time. On the other hand it would appear hazardous to the present writer to change without necessity the simple and sound foundation for the calculation of structures, more particularly iron bridges, as supplied by our present theory in favour of more complicated formulae. For a well designed bridge in none of its parts must be strained beyond the so-called limit of elasticity, and within these limits the principle of elasticity as well as the theorems relating to the distribution of stresses within an ideally uniform body, etc., as laid down by Navier and his successors, are sufficiently correct for the purposes of the designer, as has been proved again and again by a great number of experiments. *The designing engineer is only able to take into consideration certain regular or accidental variations in the behaviour of the actual building material, as compared to that of ideally uniform bodies, on which the theory of elasticity is founded, by fixing the factor of safety in each case as it occurs, according to the greater or smaller influence of the variations referred to, as estimated by himself.* By this the writer does not wish to express the opinion that all problems included in the theory of elasticity and resistance of materials have necessarily found their final solution at the present moment.

Side by side with the theory of the equilibrium of uniform bodies referred to, the calculation of girders and beams, supported in more than two places, was being slowly developed. Already *Eytelwein*, the first headmaster of the Berlin College of Architecture, in 1808 found a way of determining the abutment pressures of a beam continuous over more than three supports, later on the same problem was solved by Navier. These older methods, however, were so complicated and inconvenient, that in many cases roughly approximate calculations were found to be preferable. The first general method, at once simple and of easy application, of calculating continuous girders dates from 1857, when it was introduced by *Clapeyron* (1779—1864), who at once made use of it for the calculation of large iron bridges[20]). In Germany Clapeyron's method was published and improved in 1860 by *Mohr*[34]) later on, in 1873, extended by *Weyrauch*; a complete list of the numerous theoretical works on continuous girders was given by *Winkler*[21]).

To Clapeyron is also due the first application of the principle of work to statical problems. With great ingenuity this eminent engineer made use of the general and only condition of the equilibrium between the exterior and interior forces of an elastic body, as derived by Navier from the principle of virtual deformations, by substituting for the latter the actual elastic deformations. Assuming an initial state of the body free from strain and of a uniform temperature throughout, he thus arrives at a principle, which he has made use of later on for the theory of engine- and carriage springs. In its form $A = \frac{1}{2} \Sigma Q r$, where Q represents any exterior force and r the distance through which it moves, Lamé, while pointing out its great importance for constructive statics generally, has named it *Clapeyron's theorem*.

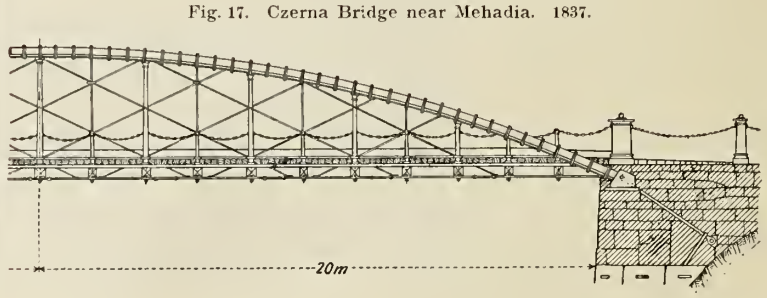
Aided by Clapeyron's formula *Castigliano*, an Italian engineer, in 1879 evolved the highly important principle of *the derivation of the work of deformation*, and deduced from this, that of the *minimum work of deformation*[22]). The theorem named last, which may also be regarded as an application of the *principle of the minimum effect*, stated in 1747 by *Maupertius*, to the theory of elasticity (see page 10), was already published in 1858 by Menabrea[23]) and in 1882 by Fränkel[24]). By means of these two theorems, referring to the deformation work of elastic bodies, Castigliano has improved *the analytical theory of statically undetermined structures* to such an extent that to-day we are enabled to solve analytically in a simple manner the most difficult problems of this kind, although occasionally the calculation of systems containing many superfluous members may still require the solution of a great number of equations and consequently a good deal of laborious work. *The calculation of statically undetermined frames* is therefore generally accomplished in a clearer and simpler manner by making use of the *graphic methods*, principally founded on *Mohr's* phenomenal work *"Beitrag zur Theorie des Fachwerks"*, published in 1874-75, further particulars of which will be found in paragraph 14.

9. THE MAIN BRACING OF GIRDERS. At present generally two kinds of bracing are distinguished:

1) The system containing *vertical* as well as *diagonal* bars and
2) The system with *diagonal* bars only.

In either case the lattice may consist of a single or a multiple system of bars.

Fig. 17. Czerna Bridge near Mehadia. 1837.



The bracing with verticals was the one in earliest use, being as far as known first adopted for iron *bowstring girders* in imitation of timber structures (see page 9).

Messrs. *Hoffmann* and *Madersbach*, two Hungarian ironmasters, as early as 1833 built an iron bridge at Lugos, the cast iron arched top flange of which was tied at the platform level by means of a chain, which took the

horizontal thrust. In 1837 they constructed the well-known *Czerna Bridge* near *Mehadia*[25]), which has bow-string girders of 40 metres (131 feet) span, the bottom flange being composed of links, while the main bracing, as shown in fig. 17, consists of vertical posts stiffened by lattice work. The sections of the cast iron tube-shaped flanges were dimensioned according to the results of Rennie's experiments. The Czerna Bridge has sometimes been wrongly described as the first *parabolic girder bridge*. Its designers, however, who classified it as a "*cylinder-arch-suspension bridge*", were far from possessing any knowledge of the theory and calculation of parabolic girders; this is sufficiently proved by the fact that they considered it necessary to anchor the bridge down at the abutments. According to our present views the Czerna Bridge is best described as a "tied arch".

The first American iron parabolic girders were constructed by *Murphy Whipple* in 1840, the first English one being *Harrison's* well-known railway bridge over the Ouse, built in 1844. Culmann and Henz[26]) in their works, published in 1849—59, have related in detail, to what extent parabolic girders with diagonal bracing had been adopted in England and even more so in America, before people knew how to calculate them accurately.

When Culmann and Schwedler in 1851—52 published their first calculations of braced girders, the Britannia Bridge had just been opened (in 1849) and the preliminary work for the construction of the old Dirschau Bridge was being proceeded with. Both these eminent theorists at once expressed their doubts about the admissibility of high plategirders as well as close lattice bracing for important bridges. They stated that in the first case the waste of material was apparent to everybody, while in addition the high webs offered a considerable area to the windforces and tended to induce objectionable irregularities in the distribution of strains, when exposed to the sunrays on one side. In the case of close lattice girders the accurate determination of the strains was next to impossible. Both of them strongly recommended a rational division of the girders into separate panels, as it had already been carried into effect since 1846 in a few cases of smaller spans.

In 1846 *Neville*, a Belgian engineer, came forward with his system of single diagonals for bridges, which consisted of true triangular frames, though the nodes were indifferently designed and above all not truly centred. With the exception of Austria, this system has not found any extension worth mentioning, its constructive shortcomings, pointed out first by Culmann in 1852, becoming soon apparent. Neville himself took great pains, though in vain, to get his system adopted in Berlin for the proposed Vistula Bridges as well as for the bridge over the Rhine at Cologne. In 1850 he had handed in his tenders, supported by personal interviews, to Mr. von der Heydt, then secretary of state for trade and public works, in which he proposed a bridge of his system for the Dirschau site with one river span of 460 feet (144,4 metres) in the clear, consisting of four main girders, carrying three platforms, viz. a central one, 14 feet (4,4 metres) wide, for the railway line, and two side ones, each 13 feet (4,1 metres) wide, for the roadway. At the same time he offered to hand in free of charge a model of the bridge in $^{1}/_{24}$th natural size and by this means to have the stability of his system tested by experts[60]).

Fig. 18. Ohio-Falls Bridge near Louisville. 1870.

Already before this time (in 1849) *Warren*, an Englishman, had improved the constructive details of Neville's system principally by carrying through the cast iron top flange and, introducing *pin connections* of the kind, which later on have become typical of American iron bridges. The best known among European examples of the Neville-Warren system are the *Trent Bridge* of the Great Northern Railway at *Newark*, built in 1851 in one span of 73 metres (239 feet) and the *Crumlin Viaduct* on the Newport—Hereford Railway, built in 1853, the ten 46 metres (150 feet) spans of which were bridged entirely by *wrought iron* girders supported on iron piers of great height, a new constructive feature at that time. Fink's Ohio-Falls Bridge near Louisville, being at the time of its construction (1870) the widest span in America, with openings of 113 metres (371 feet) and 122 metres (400 feet), shows the Warren type with some additional stays put in (see fig. 18).

While in case of Neville's system, when applied to greater spans like the Ohio-Falls Bridge, a division of the large panels became necessary and consequently the meshes of the lattice were reduced in size, the tendency in case of lattice girders with a close division on the contrary went towards enlargement of the meshes, though at first probably without any tangible reason. In this way the so-called *multiple systems* of lattice girders originated, which, following Schwedler's precedent (in 1851), were generally calculated by means of dividing them into their separate systems and treating the load in a similar manner. With lattice girders of very close division this method of calculation cannot of course be carried through, because the platform loads are immediately acting only in the nodes of some of the several systems of diagonals, into which the lattice can be devided, and consequently the remaining nodes can obtain their part of the load only by the flanges getting deflected between them. Winkler in 1859 tried to find out a more satisfactory method of calculating girders of this kind; to-day we are enabled by means of the general theory of statically undetermined systems to deal with them in a strictly scientific manner.

Simultaneously with Neville's lattice system of single division parallel girders with *crossed diagonals as well as verticals* made their appearance. As far as Europe is concerned, the precedent of Howe's girder system was closely followed for more than ten years, counter diagonals being put into *all panels*. On the other hand, the first American so-called *Whipple girder*, built in 1848, already had inclined end verticals and *no counter diagonals in the end panels*, an innovation founded on a clear comprehension of the fact that in case of parallel-girders a certain number only of the central bays is strained by alternately positive and negative shearing forces. The

first example of this system to be met with in Europe is the Ilmenau Bridge at Bienenbüttel, designed by *von Kaven* in 1859[27]). Two years before Schwedler's Flackensee Bridge on the Niederschlesisch-Märkische Railway[28]) was erected with verticals and crossed diagonals in each panel, a system less satisfactory than that with crossed diagonals only, and decidedly inferior to that showing single diagonals and verticals. It was mentioned before

Fig. 19. Glasträger Bridge by Engesser. 1890.

that Schwedler used to calculate these and similar girders by dividing them into their several bracing systems, each obtaining its part of the load; he soon became aware, however, of the errors this mode of proceeding might give rise to, a fact proved in 1874 by *Mohr*[29]). *Winkler*, again, calculated structures of this kind — as, for instance, the bridges of the Linksrheinische Railway over the Moselle at Coblenz and over the Nahe at Bingen (compare table I, 14 and 18) — omitting the verticals altogether, regarding them simply as a mean of supporting the platform.

The principle of counter diagonals, successfully applied to timber bridges by Howe, is at present being more and more given up in case of larger spans. And rightly so. For the effect of counter diagonals, as assumed by theory, has only been imperfectly attained in practice, as it is practically impossible to put them in without any initial strain. Moreover, even in those panels of a girder, where the counter diagonals have been left out as theoretically superfluous, the main diagonals may occasionally still be strained in compression, though they are unable to resist it by reason of their flat section. This indeed has happened in many cases, where incorrect assumptions of live or dead loads had been made for calculation, or in consequence of some unforeseen increase in the live load beyond the original assumptions. For these reasons larger spans at present are preferably designed with a main bracing containing no counter diagonals at all, the majority of the diagonals being consequently strained alternately in tension and compression, and being made capable of resisting buckling.

In American bridges counter diagonals still play a greater part than in Europe. American girder types, as shown in fig. 20 to 24, generally are based on the Warren system or designed as girders with vertical posts and tensile diagonals, provided with a number of supplementary bars

Fig. 20. Pratt girder.

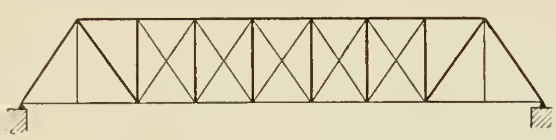


Fig. 21. Whipple girder or Pratt girder of double division.

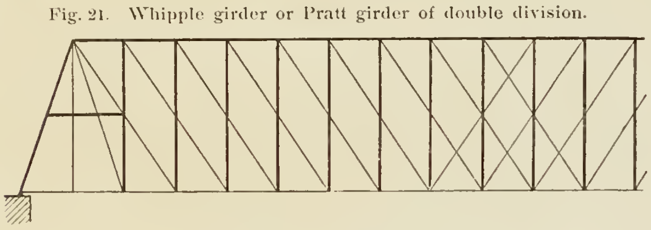


Fig. 22. Pettit girder.

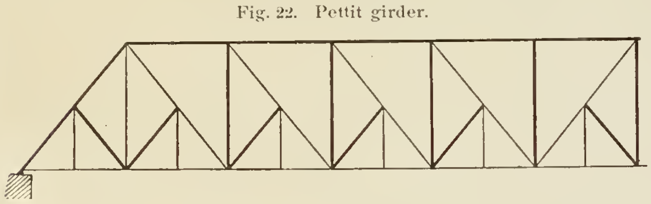


Fig. 23. Pettit girder for wide spans.

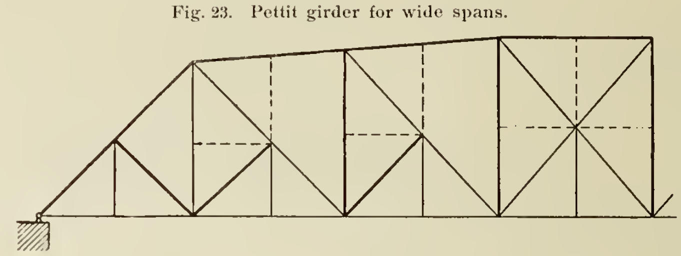
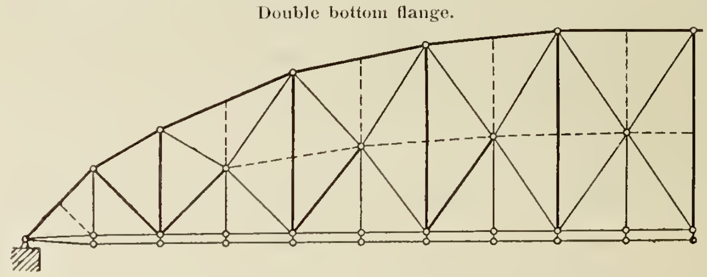


Fig. 24. Ohio Brigde near Wheeling. 159 metres (522 feet) span. Height one sixth. Double bottom flange.



During the further development of the main bracing for bridges, the system with verticals and crossed diagonals just referred to has gradually given way to that with diagonals only. Just at present *systems of single division without any counter diagonals* are being preferred, next to them that with crossed diagonals without verticals, recommended since 1851 by Schwedler, also for girders with curved flanges. The disadvantages peculiar to the system mentioned last, consisting chiefly in the very irregular straining and deflection of the different systems under the action of single loads, can according to Köpcke and Schwedler be lessened by inserting an intermediate flange (see fig. 25 and 32). The draw back of the system being statically undetermined, can too be got rid of in a simple manner by arranging the girder unsymmetrically, as shown first by *Engesser* (see fig. 19). It was first pointed out by the writer, how multiple diagonal systems generally can be made statically determined by making the diagonals run from one corner of the end vertical *uninterruptedly* through the whole girder to the opposite corner[30]).

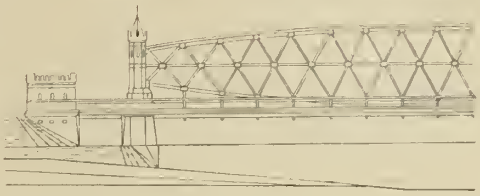
for carrying the platform or for holding compression members (see the bars shown in dotted lines in fig. 23 and 24). Their distinctive features compared with European designs are mainly the result of the well-known American manner of building up all main girders for iron bridges by means of *pin connections* at the nodes, a mode of construction, which has been adopted much less for theoretical than for practical reasons, the erection of structures in sparsely populated districts becoming thereby much simplified. In Europe, where any lack of skilled erectors and workmen is out of question, bridge designers consequently have not the same reason for adopting pin bridges and up to the present continue to adhere to rivetted connections. Now pins undoubtedly are somewhat sensitive to changes in the direction of the strain, and American designers therefore avoid as much as possible all bars strained alternately in tension and compression, admitting as a rule only pure compression and pure tension members, counter diagonals consequently becoming indispensable in case of

the central panels. With the increase in American population the bridge with pin connections only has been gradually given up in favour of a system approaching somewhat closer the European type, the top flange being now as a rule entirely rivetted up in site and the bottom flange only remaining pin-connected. Quite recently, *Morison* has designed several important bridges containing no counter diagonals, in some of the bracing bars of which consequently a change between tensile and compressive strains takes place. He thinks this to be admissible in the case of *wide spans,* because experience has proved that the pins of such girders have ceased to move at all. It is only in small spans that any considerable mobility of the pins under the influence of live loads becomes noticeable, and for this reason a few American bridge companies have recently thought it preferable to adopt the European type of rivetted trusses for structures of this kind[37]).

At the same time the true pin-system continues to be of great import in case of such countries beyond the sea, where from lack of skilled workmen any rivetting work in site is out of question.

10. THE OUTLINE OF ORDINARY BRACED GIRDERS. By ordinary girders we mean such, which are supported at two points only, and are consequently statically determined as regards their external forces. *Continuous girders* are treated in the following paragraph (11). The oldest form of the ordinary beam is represented by the *bow-string girder,* the construction of which in timber was mentioned on page 9, of iron on page 14. Its outline in most cases is a parabula, for which reason Continental designers usually call it a *parabolic girder.* A parabolic girder need not, however, like the bow-string necessarily have one straight flange; both flanges may be curved, on condition that the height of the girder at every point corresponds to the ordinates of a parabula. In that case the flanges and verticals only are being strained by

Fig. 25. Memel Bridge at Tilsit. Schwedler 1872.



uniform loads, while the whole of the diagonals remain without strain. Counter diagonals are consequently required in each panel, if a change between tension and compression is to be avoided.

Immediately following the bow-string girder, the so-called *Laves* girder (see fig. 28b), already suggested as to its principle and fundamental outline by Navier, made its appearance in 1834 and was applied to iron bridges in several instances (see fig. 13). Leaving, however, out of question the Laves girder, because in its original form it does not strictly speaking contain any main bracing at all and does not indeed require it, in case the flanges are sufficiently stiff, a circumstance already pointed out by Navier (see page 11), the bow-string type in historical order is immediately followed by the *parallel-girder.* With its end posts inclined, the latter shows the typical American outline (see fig. 20 to 24).

Fig. 26. Isar Bridge at Grosshesselohe. Pauli system. 1857.

The revival of the theory of bridges early in the fifties gave rise to a superabundance of new ideas and forms. Only such of these, however, shall be considered here, which have gained some notoriety in practical bridgebuilding. The first of these is the girder showing the outline of a *truncated lens,* later on called *polygonal girder* by Winkler. Schwedler in 1851 designed a girder of this type for the Rhine Bridge at Cologne, though he was not able to get it accepted on that occasion. At a later period this system, through Schwedler's influence,

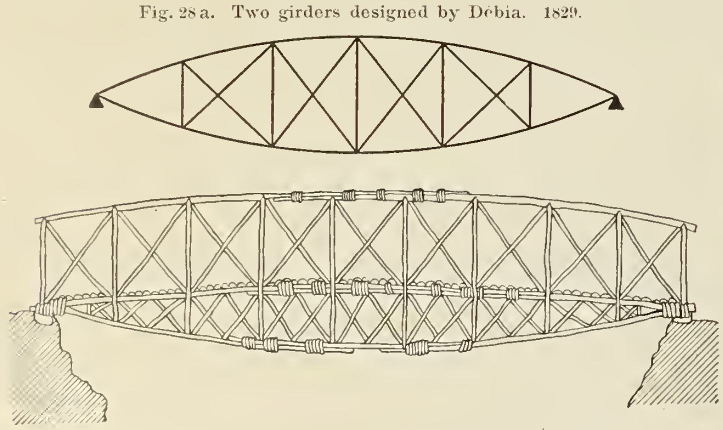
has found great favour with the Prussian State Railway authorities, who applied it to several of their most important railway bridges: the first occasion being that of the Memel Bridge at Tilsit, built 1872—75 (see fig. 25), and the last that of the new bridges over the Vistula near Dirschau and over the Nogat near Marienburg, both built 1888—93.

The first iron railway bridge in Bavaria was that erected in 1853 over the Günz at Günzburg on the Maximilian Railway (Augsburg—Ulm) with two spans of about 10 and 12 metres respectively (33 and 39 feet). It was designed by *von Pauli* (for description and drawing see next chapter) and may be regarded as a predecessor of the subsequent *Pauli girders*, which in the outline peculiar to them made their first appearance at a bridge built in 1857

Fig. 27. Saltash Bridge over the Tamar. Brunel 1854.

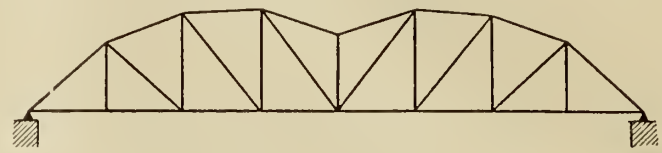
over the Isar at Grosshesselohe[61]) (see fig. 26) and attained their biggest span—viz. 105 metres (345 feet)—in case of the Rhine Bridge at Mayence, built by Gerber for the Hessian Ludwig Railway[61]). The outline of the Pauli girder

Fig. 28a. Two girders designed by Débia. 1829.



is derived from the demand of equal strain limits for both flanges. For the same reason as in the case of parabolic girders, this system requires counter diagonals in each panel, if a change in the diagonal strain between tension and compression is to be avoided. Compared to Schwedler's girders of the lens-shaped type with suspended platform (see fig. 25), the Pauli girder does not show to advantage, as far as the connection between the flanges above the points of support is concerned, because the rational design and support of the sharp point formed there by the

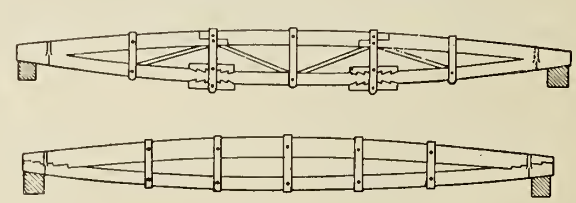
Fig. 29. Schwedler girder. Theoretical form. 1863.



flanges is a matter of some difficulty, while in the other case a substantial cross bracing between the ends of the girders is the only thing required.

Some forerunners of the Pauli type of girders—as well as of the lens-shaped girders, 139 metres (456 feet) wide of Brunel's Saltash Bridge, built between 1854 and 1859 over the Tamar near Plymouth on the Cornish Railway (see fig. 27)—may even be traced back as far as the twenties. At that time the French engineer Débia[31])

Fig. 28b. Girders of the Laves type. 1834.



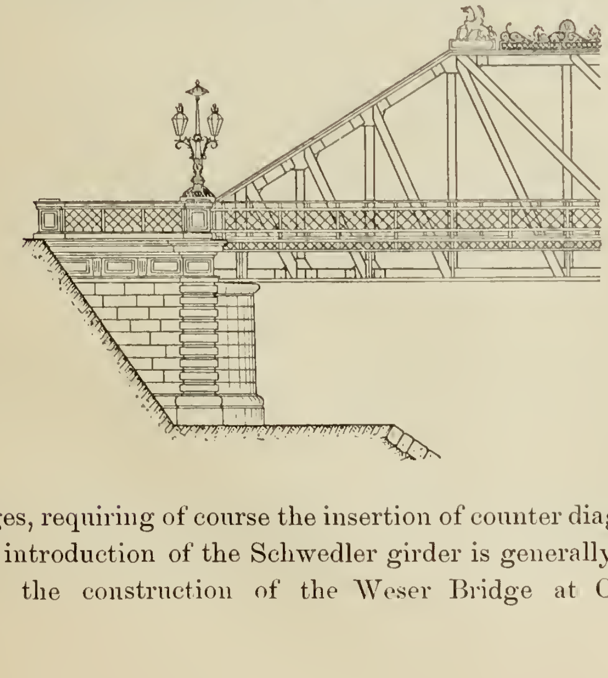
designed some bridges with a curved timber top flange and an iron chain-bottom flange, between which numerous vertical posts were fixed. Though in reality it was probably the Laves girder (see fig. 28b), which has suggested the form of the Saltash Bridge as well as that of its forerunner, the Chepstow Bridge over the Wye[32]), it cannot from the foregoing be doubted that Débia is the real inventor of the outline of the lens-shaped girder.

In his general theory of braced beams, published in 1851, Schwedler[79]) from certain conditions laid down for the strain limits of bracing bars, derives several so-called

"Standard types of girders", among which the parabolic outline of the bow-string girder and of the fishbelly girder are to be found. The parabolic girder, however, requiring counter diagonals in each of its bays, Schwedler in 1861 proposed a double system of diagonals for bow-string girders of larger span, omitting the verticals[33]). At a later period it occurred to him to curve the top flange of these girders in such a manner, that even under the most unfavourable position of the load no main diagonal could ever be strained in compression. The result was the *Schwedler girder,* the top flange of which would theoretically have to be formed of two hyperbolic parts (see fig. 29). A hyperbolic girder of this kind, however, being of a very unfavourable appearance, notably as to its central parts, Schwedler replaced these panels by such with parallel flanges, requiring of course the insertion of counter diagonals. The introduction of the Schwedler girder is generally dated from the construction of the Weser Bridge at Corvey, i. e. from 1863, although the outline of this bridge is not formed of hyperbulas, but parabulas. The more exact theoretical outline is only found later at the Elbe Bridge near Hämerten.

Fig. 30. Leck Bridge at Kuilenburg, Holland. 1868.

Fig. 31. Sophien Bridge over the Danube Canal at Vienna. Köstlin and Battig. 1871.



Girders of the Schwedler type have been extensively adopted all over the world, though according to general judgement their appearance is not altogether satisfactory. Schwedler himself being among the first to recognize this, he in 1868 proposed the adoption of a more graceful curve for the top flange, instead of forming it strictly according to theory[23]). *Laissle* chose an ellipse for the Schwedler girders of the Kolomak Bridge near Krementschug, built in 1871; *Häseler* replaced the straight central piece of the top flange by a flat curve in case of the Elbe Bridge girders at Dömitz, erected in 1876.

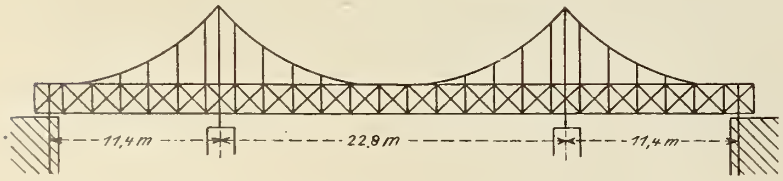
The outline of the so-called *semiparabolic girder* was, as far as known, first adopted in case of the Chepstow Bridge over the Wye, erected by Brunel in 1852. The Yssel Bridge, too, built 1853—56 near Westervoort on the Arnheim—Zevenaar line of railway, with two spans of 50 metres (164 feet) each, being the first remarkable iron bridge erected in Holland, has a top flange curved towards the ends. The outlines of large American bridge girders of more recent design nearly always show polygonal top flange, straight bottom flange and inclined end posts (see fig. 23 and 24), having a strange resemblance to the ancient German braced timber bridge, handed down to us by Palladio (see fig. 6). Who in noting this remarkable similarity is not reminded of Rabbi ben Akiba's wellknown saying?

The American example of limiting bridge girders to as few separate types as possible, simplifying their construction at the same time, has doubtless reacted to some

extent on Europe of late. Parallel- and semiparabolic girders are being preferred at present, the latter in cases of larger spans. The semiparabolic girders of the Leck Bridge at Kuilenburg*) (see fig. 30) have the widest span in Europe, viz. 154,4 metres (507 feet). For smaller spans bow-string girders are occasionally preferred, for lofty viaducts girders of the fishbelly or of the Warren type. Girders of the trapezium type, as shown in fig. 31, are rarely met with. Theoretical outlines, like parabulas, hyperbulas, ellipses etc., have rightly ceased to play any part in the design of large structures to-day, and the same may be said of counter diagonals. In contrast, however, to America, in Europe, above all in Germany, girder outlines are formed not only to satisfy purely economical requirements, but with regard to producing a favourable impression on the eye. It is for this reason that in case of curved flanges circular curves are being more and more adopted by designers. The writer in 1891 chose a circular outline for the semiparabolic girders of the Vistula Bridge at Fordon, following the advice of Jacobsthal, the principal reason being the much more favourable appearance of the wind-bracing connecting the top flanges of the maingirders as seen from the bridge itself, compared to that with the curve of the top flange changing its radius from time to time (see fig. 32). On the whole it appears of doubtful value, in determining the general outline of a structure, to adhere too closely to purely theoretical considerations or demands, in order to theoretically economize material. A good designer must be able to do more than merely calculate. Cooper[13]), the American engineer, hits the right nail on the head in saying: "True economy is not necessarily synonymous with minimum of weight".

Fig. 32. Vistula Bridge at Fordon. Interior view of the river spans. 1894.

Fig. 33. Wrsowic Bridge by Langer. 1870.



*) Constructed by the Harkort Bridge Company at Duisburg.

11. CONTINUOUS GIRDERS AND CANTILEVERS (Ausleger, porte-à-faux). The first publication of a general and lucid theory of continuous girders by *Clapeyron* was already mentioned on page 14. Mohr made this theory known to wider circles and in 1860, introducing at the same time variable heights of the supports, extended it by *proving the danger of accidental settlements at the points of support* for uniform as well as (in 1862) for varying girder sections[34]). Even at that time Mohr gave warning against overestimating the advantages of continuous girders and recommended the use of ordinary girders instead. To what degree the history of iron construction has justified his advice is well known. Ordinary braced girders are in the front rank of bridgebuilding to-day, though attempts have repeatedly been made of improving

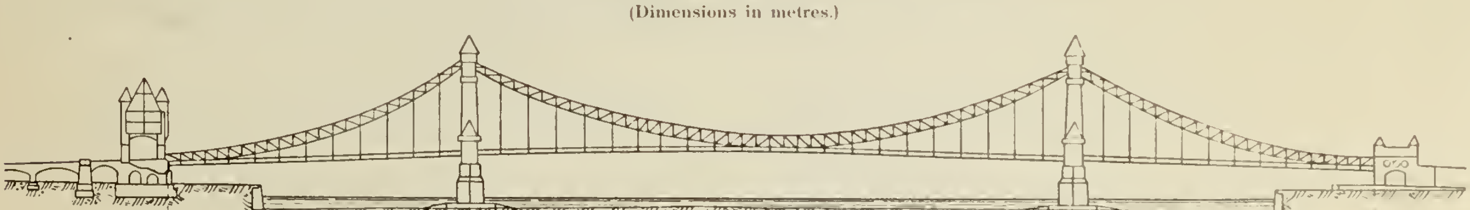
continuous girders either by fixing suspension members to them, by putting artificial loads on them or by making their outline resemble girders of uniform resistance, etc.

Josef Langer, an engineer of inventive genius, though often misunderstood at his time, was the first to stiffen a continuous girder by means of fixing to it a suspension member lying above it, in such a manner as to do away with the horizontal pull of the latter. His Wrsovic Bridge on the Francis Joseph line of railway forms a compound

Fig. 34. Mühlenthor Bridge over the Elbe-Trave Canal at Lübeck. 1899.

girder structure of this kind, producing the impression of a suspension bridge (see fig. 33). Langer himself calls it a "stiff chain-bridge anchored down vertically". A similar though at the same time very graceful design of a continuous girder, approaching in appearance a suspension bridge, was handed in by *Lauter* at the well-known Mannheim Bridge competition in 1887 (see fig. 37 C). By the

Fig. 35. Rieppel's design of a roadbridge over the Rhine at Cologne. 1898.
(Dimensions in metres.)



same means *Rehder* has given a very pleasing appearance to the Mühlenthor Bridge over the Elbe-Trave Canal at Lübeck*) (see fig. 34). A very recent design belonging to the same category was handed in at a private competition arranged by the city of Cologne in 1898 for the purpose of obtaining preliminary designs for a roadbridge over the Rhine*) (see fig. 35). Statically the main girders of the design in question represent a beam with three flanges, continuous over four supports, with its ends anchored down at the abutments. The bracing bars are between the two upper flanges only, called "Girlande" (festoon), the bottom flange being below the platform and connected to the upper girder at points near the three apices of the curve. The leading principle of this design consisted in keeping the two upper flanges as far as possible free from compressive strains or at any rate reducing the latter to comparatively small proportions, in order to facilitate the stiffening of the upper flanges, which are without any windbracing. For this reason the bridge is to be erected, starting from the two river piers, on the cantilever principle, and before it is finally joined together at the centre, is to be fully loaded with the dead load by suspending from it the whole weight of the platform. It then represents two cantilevers, the top flanges of which under any circumstances can only obtain *tensile stresses.* This state of things is not altered by inserting the central bars, because this will be done without producing initial strains of any kind. It is only when live

*) Constructed by the Harkort Bridge Company at Duisburg.

*) By the Nuremberg Engine Works L[d]., at Nuremberg.

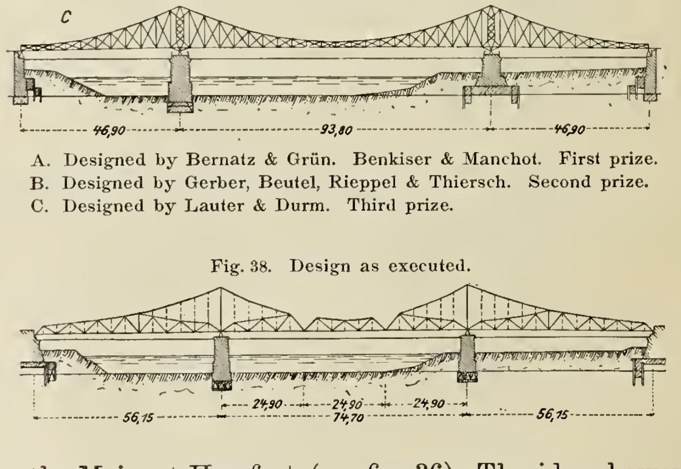
loads appear on the bridge that tension can be changed to compression in a few parts of the top flange, notably near the centre of the middle span and at the shore half of the side spans, both places not being very high above the platform level. The intermediate flange is exclusively strained in tension. The lateral stability required will be obtained without any difficulty by means of stiff connections between verticals and crossgirders, because the circumstances in this case are entirely different from those of an ordinary open bridge, with the platform below. In contrast to the latter, the girder described here, if pushed out of its plane, has the tendency to return to its vertical position, because its centre of gravity is situated below the line connecting the points of support. The lateral stiffness of the whole structure is obtained by means of suspended crossframes together with the main windbracing below the platform, which like the maingirders forms a beam continuous over four supports.

Another remarkable structure is the Stephanie Bridge at Vienna, built in 1884, the central span of which has been made to appear like an arch, while the two smaller side spans are concealed within the abutments, reducing the bending moment of the middle span by means of the *artificial load* put upon them. A similar reduction of the bending moments was obtained by *Köpcke* in 1856 by means of artificially lowering the central supports[34]. In case of the new railway bridge over the Elbe at Dresden, where in consequence of the rail level being unusually near the water level, the available constructive height was very limited, Köpcke has *concealed an artificially loaded three-hinged arch* within the southern abutment, making use of its horizontal thrust for producing a negative moment in the main girders, which, being continuous over five spans, are designed to appear outwardly like arches. Artificial expedients like these, which have also been applied already to ordinary girders, ought to be limited to special cases, where local circumstances make their application necessary. Otherwise they could only be looked at as oddities, having no claim to serious consideration.

Ruppert's design of a viaduct crossing the Bosporus, published in 1864, can also be regarded as an attempt to introduce continuous girders in cases of large spans. To form its outline two parabulas interpenetrate in a manner that the heights of the girder are in proportion to the bending moments. The system may also be looked at as a combination of arch and chain. Ruppert's design gave occasion to the introduction of a new type of girder, the so-called hinged continuous girder, usually called *cantilever.* In Germany it is sometimes called the Gerber girder, because Gerber made the first use of it for a roadbridge over the Main at Hassfurt (see fig. 36). The idea, however, of inserting hinges at those points of continuous girders of equal resistance, to be theoretically determined, in which the moments due to uniform load become nil, is considerably older. According to Westhofen[35] Clark and

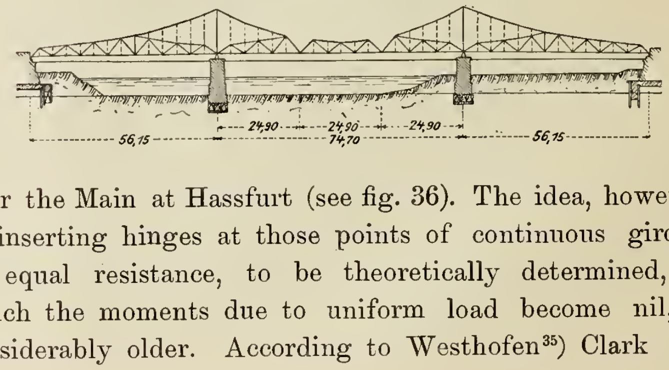
Fig. 36. Roadbridge over the Main at Hassfurt.

Fig. 37. Bridge designs of the Mannheim competition.
(Dimensions in metres.)



A. Designed by Bernatz & Grün. Benkiser & Manchot. First prize.
B. Designed by Gerber, Beutel, Rieppel & Thiersch. Second prize.
C. Designed by Lauter & Durm. Third prize.

Fig. 38. Design as executed.



Fowler are said to have already suggested it about 1846 to 1850. In Germany the first proposal in this direction was made according to Ritter by *Köpcke*, and *Ritter* himself has treated the theory of hinged continuous girders in his lectures at the Hanover technical college as far back as 1861. Different names are being applied in Germany to this type of girders to-day, while in England and America they are generally known as *cantilevers,* in France as *portes-à-faux.*

The outlines of American cantilever bridges in too many cases are remarkable by their very pronounced unsightliness. In Germany, on the contrary, great pains are being taken of giving them as pleasing and effective an outline as possible, that of suspension bridges being preferably chosen. *Brennecke* in 1879 proposed this outline for the Troitzky Bridge at Petersburg, later on *Gerber* selected a peculiar form of it for his design of the Neckar

Fig. 39. Frederick Bridge over the Neckar at Mannheim. 1890.

By means of inserting hinges continuous girders on the one hand can be made statically determined, while on the other hand some saving of material is effected. For girders supported in n places n — 2 hinges are required to make them statically determined. At first cantilevers were mainly prized on account of their being statically determined, but later on after the possibility of *erecting them without the use of fixed scaffolding, even in case of very large spans,* had been recognised, they at once became very prominent. The practical test of this possibility was first supplied by American engineers. It was above all the erection (in 1876—77) of the first American cantilever bridge of wide span, viz. the Kentucky Viaduct of the Cincinnati Southern Railroad, with a main span of 114 metres (374 feet), further that of the Niagara Cantilever Bridge of the Michigan Central Railroad, built in 1883 with a centre span of 141 metres (463 feet), which directed the attention of the whole engineering world to the new type of bridges. Its most magnificent example, however, is still represented by the cantilever bridge crossing the Firth of Forth near Queensferry in Scotland, erected in 1883—90, the two main spans of which of about 521 metres (1705 feet) each form the widest spans of any bridge in existence. The largest spans of any cantilever bridge on the Continent of Europe, viz. 190 metres (623 feet), are those of Saligny's Danube Bridge near Czernavoda in Roumania.

Roadbridge at Mannheim, when taking part in that competition in 1887, where many cantilever schemes competed (see fig. 37). The graceful design chosen for execution (see fig. 38 and 39) was made after its model*). Quite recently outlines similar to that of Ruppert's girder, showing an arch intersected by a chain, have reappeared again. The *Gutehoffnungs Works*, for instance, recently prepared a design of this kind for the main span, 220 metres (722 feet) wide, of a Rhine Bridge at Ruhrort, the system chosen enabling it to erect the superstructure without any fixed scaffolding whatever. Finally the "Kaiser-Footbridge" over the Spree at Oberschönweide near Berlin, designed in 1899 by *Müller-Breslau*, may be mentioned, having a centre span of 86 metres (282 feet) and showing a system, which may be described as a *cantilever bridge provided with a central hinge and a stiffening arch*[36]).

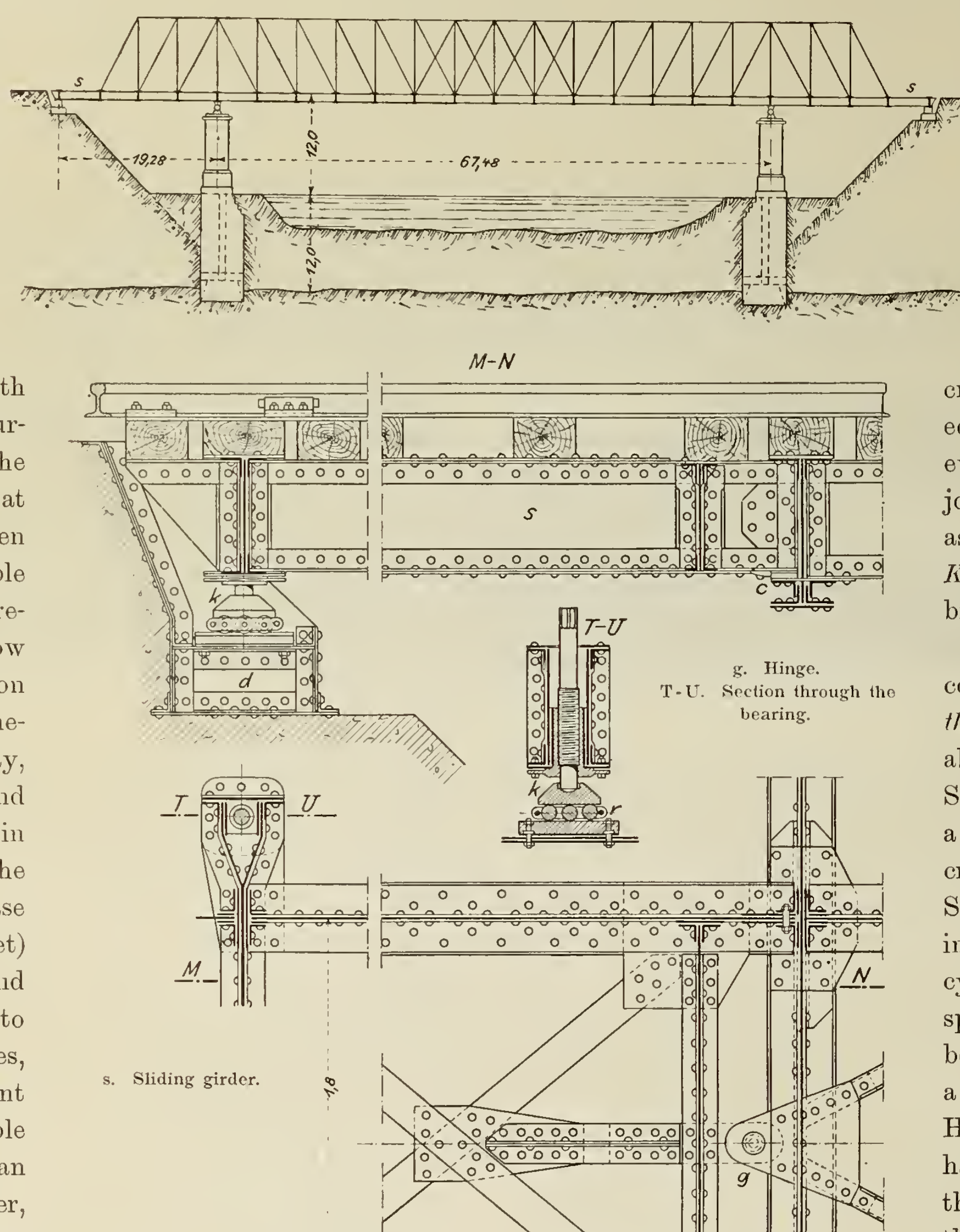
It was mentioned before that at first cantilevers were mainly prized on account of their being statically determined. It may even be asserted that this advantage was being somewhat overestimated, many designers, mistaking the proper qualities of the new girder type, being inclined to erect cantilevers wherever it was possible, even in cases of insignificant spans. In the writer's opinion, they were decidedly wrong in doing so. Efficient hinges not only are very expensive, but in addi-

*) By the Nuremberg Company.

tion have to be designed very carefully in order to fulfil their purpose, as otherwise they would do more harm than good. American experience in this respect should serve us as a warning (see pages 16 and 17), cantilever systems being scarcely ever used there for spans below about 160 metres (525 feet)[37]). The insertion of hinges in continuous girders, therefore, ought to be limited in Europe also to such cases, where they are absolutely required. In cases, where the erection of important spans is in question and fixed scaffolding is to be dispensed with, cantilevers are in their right place. Moreover, where continuous girders have to be built over foundations resting on unreliable soil, the insertion of hinges becomes advisable in order to avoid dangerous deformations of the structure in consequence of accidental subsidences or displacements.

The oldest example of hinges applied in connection with cantilevers for the purpose of reducing the abutment pressures at the end bearings, when resting on compressible soil, is probably represented by the Warnow Bridge near Rostock on the Waren — Warnemünde line of railway, designed by Seifert and Backhaus and erected in 1885*) (see fig. 40). The cantilevers in this case are 14,5 metres (48 feet) long, and the short end spans s, connected to them by means of hinges, reduce the abutment pressure at the moveable end bearings to such an extent, that the latter, formed like ordinary jack-screws, are simply resting on the gravel bed of the embankment and can occasionally be regulated in height and stopped like ordinary railway sleepers[38]).

Fig. 40. Warnow Bridge near Rostock. 1885. (Dimensions in metres.)



g. Hinge.
T-U. Section through the bearing.

s. Sliding girder.

12. ARCH BRIDGES. Arches are already found among the timber structures of the eighteenth century. Bruyère supported his footbridge near St. Crou by means of braced arches with crossed diagonals and a straight top flange. Navier in that chapter of his Constructive Mechanics, which treats bridges supported by arches, already shows a drawing of arched girders consisting of two concentric curved flanges, with a bracing of verticals and crossed diagonals between them. It is evident, however, that both these engineers had no very clear insight into the action of the bracing; the crossed diagonals were not intended to act as main and counter diagonals respectively, but simply to connect the flanges, being left out of question in the calculation of the arch.

Early in the century the idea of inserting *a hinge at the crown* has also been considered already. When a discussion was going on and investigations were proceeding concerning the replacement of old London Bridge by a cast iron arch bridge[39]), *Robeson*, the teacher of John Rennie, made the proposal (though without success) of inserting a heading piece forged of wrought iron with curved joints, at the crown, in order to counteract the influence of any settlement of the arch and the consequent increase of pressure at the edges of the joints. This evidently is a crown joint of the same kind, as was first applied by *Köpcke* in case of stone bridges.

The invention and construction of *hinges at the springing* date back about half a century. In Stephenson's design of a cast iron archbridge crossing the Menai Straits the arch was intended to be of cylindrical shape at the springing, fitting into bearings hollowed out in a corresponding manner. Hinges of this kind have been made for the cast iron bridges of the Severn Valley Railway between Shrewsbury and Bewdley, designed by *Fowler*. On this occasion already the now well-known fact was noted that a rotatory movement of the cylindrical ends of the arches within the supporting shoes does not really take place at all. Under these circumstances hinges at the springing naturally are of little value. It appears indeed necessary to have a perfect fit between the cylindrical surfaces of the top and bottom parts of the bearing, in order to keep the point of application of the abutment pressure within a strictly limited area, even in case any considerable mobility of the hinge appears unlikely on account of its friction.

The early attempt of Bruyère referred to was followed

*) By the Harkort Company at Duisburg.

by an interval lasting half a century, during which wrought iron arches were not heard of again, and cast iron arches with their girder- or tube-shaped flanges, in most cases stiffened by a bracing at the spandrel, were not able to compete with wrought iron suspension and girder bridges. During this pause in the development of arches (see page 13) the theoretical and practical foundations for the perfection of braced girders were being established and extended. The results obtained, more particularly in the construction of girder bridges, caused experiments to be made also with regard to arches. In 1853 *Stehlin* designed a full webbed archbridge of a I section, which a year later gave occasion to the construction of the Aare Bridge at Olten by *Etzel* and *Riggenbach*, a railway bridge on the Swiss Central Railway, with plate arches in three spans of 31,5 metres (103 feet) each (see fig. 41). Almost at the same time

Fig. 41. Aare Bridge at Olten. Stehlin, Etzel and Riggenbach. 1853—54.

Fig. 42. Rhine Bridge on the Coblenz Lahnstein line. Hartwich 1861.

Oudry built the Townhall- or Arcole Bridge at Paris with a boldly designed plate arch and braced spandrel, in one span of 80 metres (262 feet).

At first, following the example of stone arches, hinges were entirely dispensed with, the arch structure being consequently statically undetermined, with three unknown quantities, and nobody being yet able to calculate it accurately. The first theoretical works treating this sub-

Fig. 43. Rhine Bridge at Rheinhausen. M. Gladbach and Duisburg line. 1873.

Fig. 44. Rhine Bridge above Coblenz. Berlin and Metz line. 1879.

ject were supplied by *Ardant* in 1841, *Bresse* in 1848—51 and *Winkler* in 1856. It, therefore, appeared quite natural at the time to try and do away with at least part of this statical indeterminateness and consequently facilitate the calculation by means of inserting hinges at the springing. The first hinges of this kind, applied to wrought iron arches, were constructed in 1858 by the engineers *Couche, Mantion* and *Salle* at the railway bridge over the St. Denis Canal on the Paris and Creil line. Mantion in 1860 published the calculations referring to this case and incidentally mentions having already thought of inserting a third hinge at the crown as well. This hinge, however, was not put in after all, probably because the designers had no clear idea yet about its effect on the structure.

During the same year (1860—61) *Köpcke's* proposals concerning the insertion of a central hinge in case of stiffened suspension bridges were published[40]. As far back as 1857 Köpcke had already worked out a design of this kind, pointing out in his description of it the applicability of the central hinge, recommended by him, to archbridges as well. The merit of having first generally and in detail explained and proved the construction of the three-hinged arch cannot, therefore, be denied to him, though, as was explained above, the principle itself was already known before him. It was *Hermann*, who in 1864 completed the first three-hinged arch by providing a plate archbridge over the Wien with a hinge at the crown; Schwedler followed in 1865 with the Unterspree Bridge[41]. *Lauter*)* at the competition for the Danube Bridge near Czernavoda received the first prize for his design of a three-hinged archbridge of a span of 195 metres (646 feet).

*) Of the firm of Ph. Holzmann & Co. at Frankfort-on-Main.

Even at that time many engineers had an aversion against using hinges. Amongst these *Schmick*, late of Frankfort on the Main, may be mentioned, who in 1869 built the first stiffened suspension bridge, provided with a central hinge, at that town. *Culmann* too disputed the necessity of hinges as well as *Eads*, the designer of the well-known Mississippi Bridge at St. Louis, though later on he proposed a three-hinged arch for a bridge over the Bosporus[15]).

Fig. 45. Schwarzwasser Bridge. Berne and Schwarzenberg road. 1882.

Fig. 46. Elbe Bridge at Hamburg. Lohse system. 1868—72.

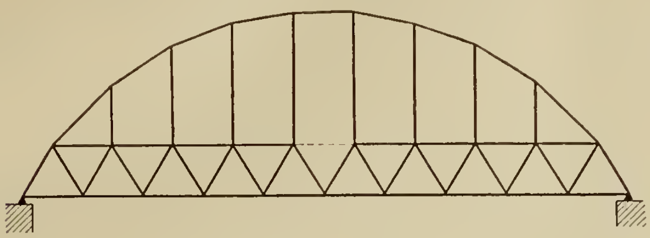
The St. Louis Bridge with its three spans, up to 158 metres (518 feet) wide, opened the series of archbridges of wide span, erected between 1860 and 1880. It is without hinges, and at that period was remarkable chiefly by the use of steel for the tube-shaped flanges of its braced

Fig. 47. Bridge over the Southern Elbe between Harburg and Wilhelmsburg 1899.

Fig. 48. Bridge over the Southern Elbe between Harburg and Wilhelmsburg. Perspective view of the interior.

arches, further by the pneumatic foundation, 31 metres (102 feet) deep, of the piers, as well as by the novel manner of its erection, accomplished for the first time and in a rational manner by means of temporary staging erected

Fig. 49. Arch stiffened by a beam, by Langer. 1871.



on the piers above the arches, from which the latter were gradually built out, fixed scaffolding over the river being, therefore, entirely dispensed with. Among the older arch-bridges of smaller span a single one only is worthy of notice by its side, viz. the Rhine Bridge on the Coblenz-Lahnstein line of railway, built by *Hartwich* in 1861 to 1864 (see fig. 42*). This structure gave occasion to a great revival of the building of arches, being the first *braced* arch with curved concentric flanges, provided with hinges at the springing. The insertion of a hinge at the crown, as proposed at first, was given up in consequence of Hartwich's protest against it. The prominent theoretical and constructive features of this bridge, the design of which was directed by *Sternberg*, exerted a very favourable influence on the different Rhine bridges built later at Rheinhausen and above Coblenz**) (see fig. 43 and 44), and on account of its very graceful outline even to-day it takes a high rank among existing archbridges.

During the sixties the development of the theory of arches visibly begins to go ahead. According to the literary tables contained in the well-known "Handbuch der Ingenieurwissenschaften"[85]), *Sternberg* was followed first by *Winkler*, subsequently by *Fränkel, Engesser, Mohr, Kübler* and others. The whole of their theoretical investigations were benefitted to a high degree by the simultaneous development of the theory of elasticity, as described above, as well as by the perfection of constructive graphics after Culmann (1866), referred to later on. The new general methods of treating statically undetermined structures do away with the difficulties and uncertainties of their calculation hitherto encountered. Incidentally designers were brought by them — though very slowly — to a better appreciation of statically undetermined systems. In suitable cases the latter are no longer put aside in favour of statically determined structures, as used to be the case before. This means a change of views, on the one hand benefitting archbridges to a considerable extent, on the other hand shaking the belief in the necessity of hinges. Among the prominent recent examples of braced arches *without hinges* the following may be mentioned: The Schwarzwasser Bridge carrying the road between Berne and Schwarzenberg, built in 1881—1882 with a span of 114 metres (374 feet), (see fig. 45); the central arch of the Aare Bridge at Berne*), finished in 1898, with a span of 117 metres (384 feet) (see fig. 179), finally the well-known Kaiser Wilhelm-Bridge**), spanning the Wupper Valley near Müngsten in one arch, 170 metres (558 feet) wide, and 107 metres (351 feet) high (see fig. 103).

To the systems already described, viz. the plate arch and the braced arch with or without hinges, in the course of the last 40 years several new ones have been added.

Fig. 50. Ferdinand Bridge over the Mur at Graz. 1881.

*) Constructed by the Harkort Company and the Cologne Engine Works at Bayenthal.

**) Constructed by the Gutehoffnungs Works.

*) Constructed by the Gutehoffnungs Works.

**) Constructed by the Nuremberg Company.

According to historical order *Lohse's* system is to be mentioned first, as applied at the Elbe Bridges at Hamburg and Harburg, erected in 1868—69 (see fig. 46). The outlines of the arched girders show the lens-type; top and bottom flange, however, each form a stiff braced arch in themselves, connected above the supports in a manner to do away with the horizontal thrust. This system is rightly considered to be antiquated at present, not only on account of its manifold statical indeterminateness, but mainly because to-day it is possible to accomplish the same purpose in a better manner and by simpler means. This is strikingly proved by a comparison with the fine road-bridge crossing the southern branch of the Elbe between Harburg and Wilhelmsburg, recently opened (see fig. 47)*), being situated very close to Lohse's bridge. The new bridge consists of stiff braced arches, lying high above the roadway, with their horizontal thrust taken by a separate tension member at the level of the platform. A similar arrangement was already made in case of the Czerna Bridge near Mehadia in Hungary, built in 1837 (see fig. 17), and of the Brook Bridge at Hamburg, built in 1888[42]). For bridges with several openings, situated among picturesque scenery, this system is admirably suited, because the suspension rods carrying the platform can be put wide apart and consequently do not interfere with the view from the bridge, further because — a sufficient height of the arch being supposed — the windbracing between the top flanges, as seen from the bridge, also presents a favourable appearance (see fig. 48). The same system was applied in case of the railway bridge over the Rhine at Worms (see fig. 110), of the Hüxterdamm Bridge over the Elbe-Trave Canal at Lübeck and of the Moselle Bridge at Trarbach**) (see fig. 107—8), further in the design of a roadbridge over the Elbe at Magdeburg***) (see fig. 111 and 112). The centre span, 187 metres (613 feet) wide, of the Rhine Bridge at Bonn†) shows the same system, but with the tension member, taking the horizontal thrust, left out (see fig. 105).

*) Constructed by the Nuremberg Company.
**) All built by the Harkort Company.
***) By the Union Works at Dortmund.
†) Constructed by the Gutehoffnungs Works.

Fig. 51. Cantilever-Archbridge over the Elbe-Trave Canal near Mölln-Schwarzenbeck. 1899.

In case of older structures an uninterrupted view through the girder was obtained by making the arch itself a mere compression member, the stiffness required to resist the live loads, as well as the horizontal thrust being provided for by a separate girder. This idea originated in 1871 with *Langer*[43]), who in addition proposed the insertion of a hinge at the centre of the stiffening beam (see fig. 49). His system (without the central hinge) was carried out for the first time in 1881 at the Ferdinand Bridge over the Mur at Graz (see fig. 50), later on by *Müller-Breslau* at the Ihme Bridge in Hanover, built in 1889*), and at the bridge carrying the road called Kurfürstendamm over the Halensee Station near Berlin, built in 1892. A disadvantage of this system in case of larger spans is found in the necessity of making the arch secure against buckling. Moreover, while in case of suspension bridges, a separate stiffening structure cannot of course be dispensed with, the writer does not think this system very suitable for arch-bridges. As the arch has to be stiffened in any case, why not at once make it sufficiently stiff in itself, instead of making it dependent on a separate girder for this purpose? If an uninterrupted view from the bridge is desired, a *stiff* arch (see fig. 48) as described above, being put high enough above the platform for its thrust to be easily provided for in a convenient manner, will solve this problem in a simpler and more satisfactory way.

If to the systems referred to before the *crescent-shaped arch* and the *cantilever-arch* are added, the list of arch systems, which up to the present have proved to be of practical value, will be completed. The true crescent-arch with hinges at the springing is theoretically found to possess a favourable outline, because the height of the crescent can be made in proportion to the corresponding bending moments. On a large scale this form was first applied by Eiffel at the Maria Pia Bridge of the Portuguese State Railways over the Douro at Porto, built in 1876 with a span of 160 metres (525 feet), further in 1880 at his Garabit Viaduct on the Marvejols-Neussarges line of railway, which has a span of 165 metres (541 feet), and, being 122 metres (400 feet) high, is at present the *highest iron bridge in*

*) By the Union Works at Dortmund.

existence. The roadbridge over the Rhein at Worms*), recently completed, also shows crescent-shaped arches (see fig. 109). A peculiar outline, suggesting a strut frame on a large scale, was given by *Max am Ende* to the arch, 70 metres (230 feet) wide, forming the centre span of the Blaauw Krantz Bridge, Cape Colony, designed by him in 1884.

The modern structures conveniently called cantilever-arches, as a rule span a central and two side openings, the main arch being extended over the latter in the form of cantilevers. Regarded as a continuous girder, provided with a hinge at one of its supports, the system is doubly undetermined, the same being the case, if the centre span is designed as a three-hinged arch, the cantilevers simply resting on their supports. The Viaur Viaduct in the South of France, with a centre span of 220 metres (722 feet) and a height of 117 metres (384 feet) above the bottom of the valley, has been constructed as a three-hinged cantilever-arch of this kind. The outline of this system appears particularly suitable for cases, where wide cuttings have to be bridged over. A case in point is that shown in fig. 51, representig a bridge over the Elbe-Trave Canal near *Mölln-Schwarzenbeck***). The central arch of this bridge originally was provided with a hinge at the crown. When, however, in the course of being tested, the hinge proved to be of unusually great mobility, it was considered preferable to replace it by a wholly rivetted connection.

*) Constructed by the Nuremberg Company.

**) Constructed by the Union Works at Dortmund (see Appendix).

In Germany, France and Switzerland, where the building of archbridges of the nineteenth century originated, their perfection has subsequently been attended to without intermission. England, on the other hand, is scarcely able to point to a single larger archbridge, in any way remarkable. America prefers girder bridges; and up to a few years ago, besides the St. Louis Bridge already mentioned, there was in existence only a single American archbridge of any importance, viz. the Washington Bridge, built in 1889 over the Harlem River at New-York. Quite recently, however, two remarkable arches — both of them replacing suspension bridges crossing the Niagara — have been constructed, one of which, viz. the roadbridge near Cliffton[44]), is conspicuous for having the widest span — 260 metres (853 feet) — of any arch in the world. A table containing arch-, suspension-, and girder bridges of wide span, built up to 1890 in all countries of the world, is to be found in the paper "Weit gespannte Strom- und Thalbrücken" by the present writer[45]). The German archbridges, erected during the latter half of the nineteenth century, will be found enumerated in tables V and VI (see also Appendix).

Fig. 52. Pont du Midi over the Sâone at Lyon. Arnodin 1888. Total length 121 metres (397 feet).

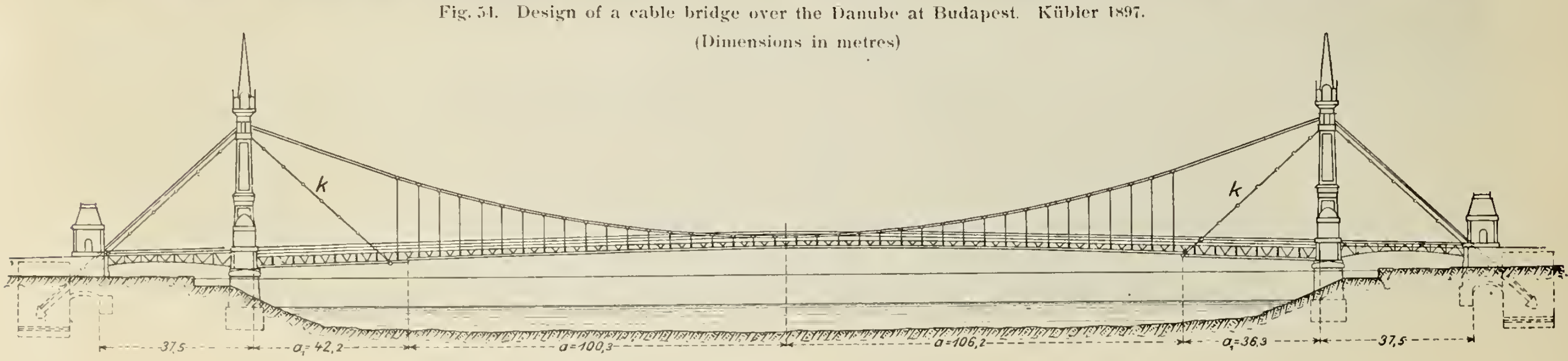
13. SUSPENSION BRIDGES. The history of suspension bridges from the primitive ropeways of prehistoric times up to the *iron* suspension bridge of *Faustus Verantius* (see fig. 1 and 2), as well as to the older systems prevailing during the first half of the nineteenth century, has been generally characterized in the preceding pages. Now the second half of the century has passed away, we

are enabled to judge what uphill work it has been for suspension bridges to gain a footing beside the ubiquitous girder. Even in North America, where for fully quarter of a century (from the fifties up to the middle of the seventies) widths above 100 metres (about 330 feet) used to be spanned almost exclusively by means of suspension bridges, prominent recent examples of the latter or improvements in their construction are now scarcely to be met with, after a long series of magnificent creations by *Röbling* father and son — beginning in 1851 with the railway bridge over the Niagara and ending in 1876 with the stupendous structure of the East River Bridge between Brooklyn and Newyork — had passed before our eyes. Even there, where they originated, suspension bridges together with all other systems formerly in use had to give way to the girder. For carrying railway traffic girder bridges easily come in first, arches being a bad second and suspension bridges simply nowhere. In Germany, for instance, Schwedler's design of a suspension bridge (see fig. 14), awarded first prize at the competition for the Rhine Bridge at Cologne in 1850, could not be got through; similarly Lentze's first design of the old Dirschau Bridge, showing a suspension bridge with five equal spans of about 158 metres (518 feet) each, though it had already been approved by the king, finally had to give way to the design of a lattice girder bridge (see page 13). On account of their inability of safely carrying any longer the heavy railway trains of recent times, the Niagara wire-bridge as well as the chainbridge over the Vienna Danube Canal (see page 12) had to be pulled down, with the result that at the present moment there is no suspension bridge, serving the traffic of a main line of railway, left anywhere in the world.

For the purpose, however, of carrying road traffic suspension bridges have gained a certain footing in a few countries, notably in America and France, after designers had learned in the meantime to remove to a considerable degree the defects peculiar to the older systems, more particularly their inconveniently great mobility under unsymmetrical loads. These so-called *stiffened* suspension bridges at present form the most suitable means of bridging large openings of 200 metres (about 650 feet) and above. In addition it has been finally proved, regarding the matter from an economical point of view, as well as for reasons of safety, that wire rope is the most suitable material for the principal parts of wide span suspension bridges of this kind, viz. for the suspension member itself and for the tie bars, by which the platform is suspended.

Fig. 53. Footbridge over the Main between Frankfort and Sachsenhausen. Schmick 1869.

Fig. 54. Design of a cable bridge over the Danube at Budapest. Kübler 1897.
(Dimensions in metres)



k: Chains connecting the hinges.

For widths of about 1000 feet even chainbridges appear unable to compete with wirebridges, much less suspension bridges with wholly rivetted flanges. It may, indeed, be asserted, that in case of important suspension bridges the choice lies only between chain and cable. If, however, for some reason or other neither of them is to be applied, it will as a rule be better to build a suitable girder bridge instead. For bridging several adjoining openings of smaller dimensions suspension bridges like arches appear unsuitable, because their horizontal pull is diminished and consequently their bending moments are increased in proportion to the number of spans. With the growing number of openings the bending moments approach those of girder bridges.

Fig. 55. Kübler's design of the Schwurplatz Bridge at Budapest. Awarded first prize. 1892.

Fig. 56. Kübler's design of a roadbridge over the Rhine at Bonn. Awarded second prize. 1894.

The first modern *stiffened suspension bridges* were constructed by John Röbling, the German-American, who in case of his celebrated Niagara Bridge, built in 1851 to 1855, enclosed the platform within braced girders of the Howe type, sufficiently strong to distribute the live loads uniformly over the suspension cable. By this means the structure obtained a comparatively great stability. Moreover, Röbling increased the resistance of his bridge against wind pressure by means of *inclining the plane of the girders* at an angle of about 1 in 20. On subsequent occasions, in addition to the strong platform girders, he made use of inclined stays, which, starting from the piers, assist in carrying the platform. These stays, in preventing the deflection of the platform at the points held by them, exert a stiffening influence on the corresponding parts of the wire cable.

At present *suspension bridges, stiffened by a beam,* following French examples (as represented in fig. 52) are being designed without the stays referred to, because the latter inevitably produce some uncertainty in the transmission of the load to the cable. The first exact calculation of a stiffened suspension bridge as a statically undetermined structure was given in 1881 by *Müller-Breslau* and *Krohn*[46]). Before that time Navier's theory of suspension members (see page 12) had to be resorted to or Culmann's and Ritter's methods were used, which are founded on somewhat erroneous assumptions. It may be mentioned

incidentally that quite recently American designers have inserted a *hinge* at the centre of the stiffening girder. This idea, however, is not a new one, having according to *Lang*[15]) already been mentioned as early as 1860 by *Schwarz* in his (unpublished) lectures.

does not always appear defensible, particularly in case of bridges, the dead weight of which is small compared to the live loads coming upon them. In case of suspension bridges, where a sufficient degree of stability is more difficult to attain than in any other kind of structure, the

Fig. 57. Point Bridge over the Monongahela at Pittsburg. Hemberle 1877.

An important innovation in the construction of stiffened suspension bridges was introduced in 1862 by *Barlow*, when building the Lambeth Bridge over the Thames in London, where he inserted a bracing of crossed diagonals between the wire cable and the platform. This was the first example of the *braced suspension bridge*, which to-day for well known reasons (see page 16) is generally designed without counter diagonals, i. e. with single diagonals only, or with single diagonals and verticals. It must be added, however, that already before the construction of the Lambeth Bridge both *Köpcke*[40]) (in 1860) and *Schwedler*[79]) (in 1861) have proposed as well as calculated the *braced suspension bridge with three hinges* as a statically determined system. The central hinge was first applied in 1869 by *Schmick*, who died a short time ago, to the footbridge, 69 metres (226 feet) wide, crossing the Main between Frankfort and Sachsenhausen (see fig. 53).

Fig. 58. Tiber Bridge at Rome. 1889.

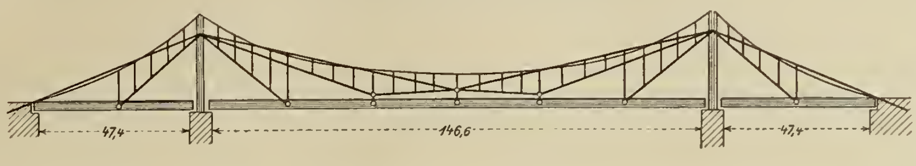
It is certainly of advantage to make a structure statically determined, because the influence of temperature on the bar stresses can be limited by that means, but to make use of a central hinge for that purpose only, disadvantages peculiar to hinges at the crown will be especially conspicuous. For the same reason the writer does not think it expedient to carry the platform on cantilevers fixed by means of hinges (see fig. 54) in order to shorten as much as possible the carrying part of the suspension structure and thereby save in cost.

The stiffening beam and the insertion of main bracing at present are the principal means of making suspension bridges really efficient. This was again proved by two prominent designs of recent date (see fig. 55 and 56), handed in by Kübler*) at the competitions for the Schwurplatz Bridge at Budapest (in 1892) and for the Rhine Bridge at Bonn (in 1894) respectively. At Budapest, the competition being an international one, Kübler was awarded first, at Bonn second prize. It is to be regretted that neither of these remarkable designs was accepted for execution. At Budapest, after hesitating four years, it was at last decided to build a chainbridge, while at Bonn the design of an archbridge (see fig. 105), handed in by the Gutehoffnungs Works and

*) of the Esslingen Engine Works.

awarded first prize, proved victorious. In both instances doubts, not wholly justified in the writer's opinion, were entertained concerning the use of cables for suspension members. In the meantime Kübler has had the satisfaction of seeing his design of a stiffened cable bridge, 72 metres (236 feet) wide, carried out at Langenargen on the Lake of Constance in 1898. For details of this bridge compare 20 and Appendix (see also fig. 115).

Fig. 59. The Ordish-Lefeuvre system.



Outline and bracing of stiffening girders for suspension bridges can be designed in a manner similar to that of recent cantilever bridges (see fig. 38 and 39). In some cases the stiffening girder has been put *above the suspension member*, the most important example of this kind being the "Point" Bridge, built in 1877 over the Monongahela at Pittsburg with a middle span of 244 metres (810 feet) (see fig. 57). It is provided with a central hinge, a new feature in America at the time, and *crescent-shaped* stiffening girders with crossed diagonals. The straight top flange of the crescent girder is strained in compression under certain conditions of the load. To avoid this *Köpcke* has proposed the adoption of crescent-girders with both flanges curved according to hyperbulas, as they have already been applied in case of two European suspension bridges of recent construction: a Tiber Bridge at Rome (see fig. 58) dating from 1889, and the side spans of the Tower Bridge over the Thames at London, completed in 1895.

Besides the more important systems of stiffened suspension bridges already referred to, several special structures or designs remain to be mentioned. In historical order these are the systems of *Ordish-Lefeuvre*, *Fives-Lille*, *Köpcke* and *Lindenthal*. On the Ordish-Lefeuvre system (see fig. 59) the Francis-Joseph Bridge over the Moldau at Prague and the Albert Bridge over the Thames at Chelsea, London, were built in 1868 and 1873 respectively. The former, however, with a centre span of about 147 metres (482 feet), has in the meantime become so ricketty that in 1898 it was considered necessary to replace its unsuitably long and straight flat bars by wire ropes, as well as to strengthen it in other ways*).

Fig. 60. Augarten Bridge at Vienna. 61,5 metres (201' 10") span. Fives-Lille 1873.

The Augarten Bridge at Vienna (see fig. 60), built in 1873 on the *Fives-Lille* system, outwardly produces the impression of a girder bridge, showing a main bracing between parallel flanges. The platform, however, is being supported by straight flat bars starting from the end verticals, a mode of construction making it necessary to tie the structure back by means of chains during erection. As soon as the top compression member has been put in, the horizontal thrust is taken by it, and the back chains can be dispensed with. The structure can be considered as a suspension bridge, because the horizontal force taken by the top flange has to be calculated like that of a suspension bridge.

*) Carried out by Felten & Guilleaume at Mülheim-on-Rhine.

At the Loschwitz suspension bridge (see fig. 61), which has a centre span of 147 metres (482 feet) and a double system of diagonals, *Köpcke* has introduced several new features, viz.: 1) Transference of the central hinge to the theoretical point of intersection of top and bottom flange below the platform; 2) substitution of springs (made of steel plates) for the three hinges; 3) the connection of the two half girders of the centre span to the iron piers, the latter resting on hinged roller bearings, with the result that in case of rising temperature they become inclined towards the centre of the bridge; 4) the introduction of *artificially loaded anchorages* within the abutments for the purpose of transmitting the horizontal forces to the ground. In addition an artificial *brake* has been provided in order to limit the action of the hinges to such load conditions, which produce stresses beyond a certain fixed limit; without these brakes the hinges consequently would show a greater mobility. Their immediate purpose consists in counteracting *vibrations* of the structure under the impact produced by persons or numbers of persons marching across the bridge.

Fig. 61. Bridge over the Elbe between Loschwitz and Blasewitz near Dresden. Köpcke 1893.

The innovations referred to undoubtedly are of great theoretical interest. At the same time the Loschwitz Bridge on account of the unattractive outline of its wholly rivetted, heavy top flanges in connection with its unusually great pitch of about one sixth of the span, and the unsightly stiffening of the central hinge by means of pieces of girders, cannot from an aesthetic point of view be regarded as a successful piece of work. With regard to the *artificial limitation of the horizontal pull*, in the writer's opinion there was no necessity for it from reasons of safety. A still safer and at the same time simpler structure *without any external horizontal force* at all would have been obtained by the construction of a cantilever bridge instead, the outline of which, if formed like that of a suspension bridge (see fig. 38 and 39), in addition would have presented a much more favourable appearance, being in better harmony with the surrounding landscape, than the existing structure.

The stupendous design of the German-American Lindenthal for a cable bridge across the North River in Newyork, with a centre span of 945 metres (3100 feet), has been made known in engineering circles by numerous publications dating back a few years. There being no occasion of referring again to this design later on, some particulars regarding its principal constructive details may be mentioned here. Lindenthal has the intention of giving his suspension cables the form of a *double chain* of a kind similar to those of the old Weser Bridge near Hameln, designed by *Wendelstadt*, and of the railway bridge over the Danube Canal at Vienna, by *Schnirch* (see page 12). The drawbacks of the double chain system, more particularly its excessive mobility, he intends to do away with by inserting angle-levers at the hinge-like bearings of the cables on top of the piers. Besides, no ordinary cables like those of the Brooklyn Bridge will be used, but a *chain* consisting, as it were, of *separate lengths of wire cable,* joined together by means of steel shoes and vertical joint plates, provided with pin connections. These links are to be ready made at the works, subsequently to be tested by special machinery and simply joined together in site. Each chain of the suspension cable will consist of four of these links and be enclosed over its entire length within a watertight steel tube, one eighth of an inch thick, protecting it against the rain and in addition counteracting any irregular extension of the wire links in consequence of the heat of the sun[47]).

Modern bridge engineering being, as will be gathered from the foregoing, on the point of doing away with the defects peculiar to older suspension bridges, it is scarcely to be wondered at, that the interest taken in this system is at last beginning to increase again. As far as Germany

is concerned, this interest has manifested itself on several occasions, notably at the bridge competitions, already referred to, of Budapest, Bonn, Worms and Cologne. At Worms for instance two remarkable designs of chainbridges were sent in, one of them by *Rieppel**), with a lower stiffening beam continuous over four piers, the other by *Lauter, Luck* and *Rieppel***), with the stiffening girders on top[48]). Although in the majority of cases suspension bridges so far did not prove victorious on occasions like these, the sharp competition entered into with other systems provided favourable opportunities for perfecting their constructive details. What improvements have been made in them up to the present, will be more fully described in the following chapter (see 20).

14. CONSTRUCTIVE STATICS AT THE PRESENT TIME. The important works by Müller-Breslau, entitled "die graphische Statik der Baukonstruktionen" and "die neueren Methoden der Festigkeitslehre und der Statik der Baukonstruktionen", being widely known throughout the Continent of Europe, contain the entire present foundation of the theory of bridges and, as regards true scientific spirit as well as exhaustive treatment of the subject, have not their equals in the technical literature of any country. If, therefore, Müller-Breslau names his first work "Constructive *graphics*", though the solutions supplied by him have not in all cases been obtained by graphic, but occasionally by analytical treatment as well, he intends to suggest that to-day the graphic methods of constructive statics form the more important part of this branch of science. This indeed is the case. For it is not only for the purpose of determining *stresses* and *deformations* in statically determined, but equally for the calculation of undetermined structures that the graphic methods at present take the first place. The only exception is formed by the treatment of structures, the whole or part of the loads of which do not act at the nodes, which consequently can no longer be regarded as true bar systems, because bending strains occur side by side with the axial stresses. Systems of this kind are best treated analytically according to the theorem of *the minimum work of deformation*, referred to before (see page 14).

The reason, why graphic methods are being preferred, will be fully understood by everyone, who by means of a good deal of exercise and by comparing their results with those of analytical calculations, has come to appreciate their simplicity, clearness and accuracy. By drawing *polygons of forces* and *funicular curves* in connection with *curves of influence, elastic lines* and *diagrams of deformation*, the most difficult statical problems can be solved to-day. The graphic plan obtained in this way offers the advantage of showing in a peculiarly lucid manner the entire action of the forces, more particularly the loads to be applied, their most unfavourable position and the stresses as well as deformations resulting from them, an advantage wholly absent in case of analytical treatment. Thus the graphic method offers an excellent means of comprehending and tracing in a diagram the variation of forces in a structure under the influence of changing loads.

*) of the Nuremberg Company.

**) of the firm of Ph. Holzmann & Co. and the Nuremberg Company.

At the same time the graphic treatment in each separate case either contains a *control in itself*, as for instance the *Maxwell-Cremona* diagram, or else it admits of being checked as to its accuracy in different ways and in a simple manner.

Exaggerated assertions have been made regarding the inaccuracy of figures obtained by graphic calculation. While it is doubtless true that absolute mathematical exactness can only be obtained by analytical, never by graphical methods, it should not be forgotten that the practical engineer does not as a rule require figures of mathematical accuracy. Experienced designers do not calculate with many decimals, they round their strain-figures in a reasonable manner. The question, therefore, whether the figures obtained by means of graphic treatment, and duly checked, are of sufficient accuracy to be used without endangering the safety of the structures designed and built according to them, can be certainly answered in the affirmative. In certain instances analytical checks may appear desirable, but they are really unnecessary in case the graphic calculation has been duly controlled.

As the real founder of the science of graphical statics Culmann (1821—81) must be regarded, who had already been treating the new methods in his lectures at the Zürich technical college, before he in 1866 published his well-known work "Graphische Statik". A short time before Culmann's book came out, *Ritter* in 1863 published the first edition of his work on the calculation of roof and bridge trusses, which has proved of high value to the development of the *analytical* theory of statically determined girders. The method, principally employed in it, of calculating structures by "*taking moments*" round a fulcrum, had been used by him already much earlier in his lectures at the Hanover college; later on it was given in a graphic form by Culmann. For the rest his predecessors *Stevin, Varignon, Lamé, Clapeyron* (see page 14), *Poncelet, Möbius* and *Cousinery* have only supplied Culmann with on the whole unimportant contributions. Stevin and Varignon were already able to draw the polygon of forces and the funicular curve (see page 10); Lamé and Clapeyron in 1827 made use of these for drawing the catenary required for the design of a chainbridge, 311 metres (1020 feet) wide, at Petersburg; Poncelet, Möbius (in 1837) and Cousinery (in 1838) were the first to apply geometry to investigations of stability. The German Möbius, as far as known, published the first general studies concerning the *rigidity or immobility of bar systems*, proving even at that time, how under certain conditions an *infinitely small mobility* becomes possible.

Culmann was the first to recognize the great importance of the relations existing between force- and funicular polygons and made use of them independently for the solution of numerous problems of practical engineering. After Culmann above all the German *Mohr* is to be mentioned, a contemporary of the Englishman *Maxwell*[49]), who in 1864 discovered the theorem of *the reciprocity of deformations* and supplied the basis, extended later on by the Italian *Cremona*[50]), for the theorems concerning *reciprocal force diagrams*. Not to mention many other highly important works, already referred to before (see page 14),

engineering science owes to Mohr the *foundations for the calculation of statically undetermined systems.*

Mohr[51]) in 1868 treated the elastic line as a funicular polygon and by this means discovered a method for the graphical calculation of continuous girders. In the same year (simultaneously with *Winkler*) he first made use of *curves of influence* as a means of determining the most unfavourable position of the loads in case of statically undetermined girders. Next to the force- and funicular polygons already referred to, the curves of influence at present form the most valuable means of solving statical problems. In 1874—75 Mohr gave the first comprehensive *theory of statically undetermined bar systems*, based on the theorem of virtual deformations (see page 10). In this highly important work he made use of Maxwell's theorem (without however being aware of it) for the purpose of obtaining the *curve of influence for the deformation of a node of the frame*, at the same time treating the *elastic line of the bar frame as a funicular polygon* for the first time. With this he had also solved the important problem of determining the greatest deflection of a node under a live load. In 1877 the Frenchman *Williot* followed with his deformation diagrams. *Krohn* in 1884 applied the theorem of the reciprocity of deformations independently of the writers referred to[52]).

Mohr's characterization of the *stiffnes of a frame* with k nodes, dating from 1871 and reading as follows: "An ordinary plain frame (i. e. one containing 2 k—3 bars) is to be regarded as stiff, in case the lengths of all bars are independent of each other", combines exactness withlucidity and brevity. It is simpler than Maxwell's definition (dating from 1864) and more accurate than that of Culmann, who only takes into account true triangular bar frames, though in a few instances it may not be quite easy to recognize the mutual independence of the lengths of the bars, emphasized by Mohr. Among other valuable works by Mohr the following may be mentioned: "Theorie der Holz- und Eisenkonstruktionen", published in 1870 and again in 1887, and the "Theorie der Bogenfachwerks-Träger", of 1874 and 1881.

A number of other prominent theorists has since been endeavouring to improve and extend the basis for constructive statics, referred to above in a comprehensive manner, as well as for the theory of elasticity closely allied with it. Their names and works are enumerated by *Müller-Breslau*[53]). It may be permitted to the writer on this occasion to pay his tribute to that among German engineers, who at his time (1873—81) has presented us with some of the most extensive and important works referring to the theory of bridges, viz. to *Winkler*, whose "Lectures on bridge construction", known among engineers of all countries, even to-day are unsurpassed for their genuine merit and thoroughness.

As an epilogue the attempts may be referred to of applying the results of the *geometrical theory of motion*, as originated in 1835 by Ampère, to the calculation of bar systems. *Fränkel* in 1875 made use of the theorems of the instantaneous fulcrum for determining the deformation of bar frames at the nodes[54]). *Föppl* (in 1880), *Müller-Breslau*, *Land* (in 1888) and *Grübler* (in 1887—89) extended the sphere of their application, more particularly to researches concerning the stiffness of bar frames. The methods referred to are doubtless of scientific value, being moreover very suitable for intuitive instruction; but it appears to the writer — though views to the contrary have also been stated[56]) — that compared to the simpler and more accurate methods of Ritter, Culmann, Cremona and others, they are of inferior practical value, as far as the determination of *stresses* is concerned.

A few special branches of bridge theory, not mentioned before, as for instance *bar systems in space, secondary strains* and *admissible strains* will be referred to in the following chapter.

III.

Improvements in the construction of iron bridges.

15. THE DESIGN. In the preceding pages the theoretical side of our subject has been chiefly treated, the constructive part being only mentioned in so far as in comparing different girder systems some reference to their construction appeared unavoidable. It was further explained that braced girders in order to make them accessible to simple theoretical treatment, have to be regarded as rigid geometrical bar systems within a plane. For the purpose of their calculation certain assumptions must be made, which, however, are not wholly realised in the actual structure. The entire skeleton of a bridge, consisting of the *main girders*, the *cross construction* and the *platform*, theoretically therefore represents a rigid bar frame in *space*. It can, however, only become ready for practical use by the designer putting the stamp of his individuality on it and inspiring it with his breath, as it were, so that the finished work may appear in a form at once suited to the locality and the object in view, at the same time warranting its *durability* and *safety*. From all this it will be gathered, how much more difficult it is to comprehend and solve the constructive problems of bridge-building than those belonging to theory. A good designer not only has to be a good theorist as well, but in addition should be in possession of something more, not necessarily clashing with the demands of pure science, viz. the faculty either inborn or acquired by practice, of nicely judging the necessity or suitability of the forms to be created by him. In other words, a designer should master the art as well as the science of his profession.

It is quite possible for an excellent theorist to be a very indifferent designer at the same time. A particularly dangerous influence has been exerted by those theorists, who obstinately persist in carrying into effect everything appearing theoretically perfect to them, without paying the least regard to the requirements of each case, which often put a practical limit to such tendencies. Professional men of this frame of mind ought to take to heart Schwedler's beautiful words, to be found in his first important theoretical work, published in 1851: "The preceding remarks have only been made in order to make it clear that a theory based on definite assumptions cannot be applied to actual structures, before it has been duly ascertained, if the whole of these assumptions are really admissible in case of the work in hand. On the contrary, it will frequently be found that theory has to be modified in case of each structure according to its material, the degree of elasticity possessed by the latter, the section of all its parts, the details of the connections and a number of other circumstances, in order to avoid grave errors. Theory generally speaking only supplies the form and method, according to which the stability of a structure has to be thoroughly thought out. It remains to the designer to fill up this form with his own ideas in each particular instance." That man, who thoroughly takes to heart this excellent advice and acts accordingly, will be the ideal designer!

During the first part of the century the working out of constructive designs fell to the lot of a chosen few of the profession; later on, when railways began to extend, the necessity arose for each railway board of securing a staff of engineers to superintend the building and maintenance of its iron bridges. Even during the fifties and sixties, however, there was a great lack of men, who had gained some measure of experience in this branch of engineering and in addition were in possession of the required theoretical knowledge. These matters visibly improved with the rise of the great German technical colleges. Above all those of Hanover, Zürich, Munich and Karlsruhe in the course of time trained a considerable number of students, who had chosen this branch of engineering for their special study, and in later years became eminently skilled in it. A peculiar contrast to these institutions was formed by the Royal College of Architecture (Königliche Bauakademie) at Berlin, at which the traditional cultivation of architecture and fine arts continued to take the lead, engineering science being comparatively neglected. Even towards the end of the seventies, when the two colleges of "Architecture" and of "Industry" (Gewerbeakademie) had already been united to form a large technical "Hochschule" of the approved German type, at which among other eminent teachers, *Winkler* and *Göring* were lecturing, the older class of the profession still continued to hold the art of bridge design in little regard. At that period the working out of

designs for iron bridges as well as iron permanent way for the Prussian railway department as a matter of course fell to the lot of mechanical engineers. The same state of things still prevailed at Bromberg, where on Schwedler's recommendation the author in 1888 had taken over the direction of the designing department for the construction of the new Vistula bridges. On this point Schwedler used to launch out into excited and rather violent expressions, better left unreported, but culminating in the exclamation: "There must be an end of this!" A change, however, came only, after the necessary separation between the departments of civil and mechanical engineering at the German technical Colleges had been carried into effect. first contributing their share of carrying it to a high state of efficiency, and later on the large German bridge companies, provided as they are with an imposing staff of engineers, thoroughly trained theoretically and practically, advancing the entire field of iron construction. In the course of time the working out of designs has gone from the hands of the few to the hands of the many, and finally under the pressure of the high demands made by modern times, which a single individual is no longer able to satisfy, has become the monopoly of the bridge companies referred to. With this state of things the building departments too have reason to be satisfied. If well advised, they will be content to draw up the building

Fig. 62. Portals of the old and the new bridge at Dirschau. Stüler 1859 and Jacobsthal 1891.

It was only after this event had taken place, that the well-known Berlin nickname of "rivethead", applied indiscriminately to mechanical engineers and to such among civil engineers, as concerned themselves "too much" about iron, began to fall into oblivion. In 1890, however, it still happened to the writer, while travelling to Scotland in company of a number of German brother engineers, in order to attend the opening festivities of the Forth Bridge, that the elegant epithet referred to was undeservedly thrown at his head by a young and spirited colleague.

The time, therefore, when designs of iron structures were not as a rule willingly entrusted to civil engineers, has not been gone very long. The more surprising are the rapid strides German bridgebuilding has since taken during the short period of the last twenty years (compare tables IV and V), the "rivetheads" among civil engineers scheme and the preliminary design, or in case of a competition decide about the plan best fitted for execution, but for the rest leave everything to the works found to be trustworthy, merely supervising the different operations taking place at the rolling mill, the erecting shops and on site.

During the last twenty years the whole field of German bridgebuilding has been thrown open in a surprising degree to the *architectural art.* From this it must not be inferred that in the case of older structures the attainment of an artistic architectural effect should have been entirely lost sight of. That would be decidedly incorrect. In looking for instance at the portal-gates of the old Vistula Bridge at Dirschau, of the old Rhinebridge at Kehl, and those of Lohse's Elbe Bridges, as represented in figures 62, 63 and 46, it will be noted that as far back as the fifties

and sixties it was considered of importance to provide the structure with a dignified architectural exterior. But during the haste and hurry of the subsequent railway boom, partly also from lack of capital and for other reasons, the readiness noticeable at first of seeking the cooperation of architects for engineering buildings, had frequently become weakened or suppressed altogether. More and more it became the custom to judge all structures almost exclusively from the point of view of practical utility and suitability, with the result that of the many thousands of unattractive bridges since created, the few handsome ones referred to form but a very small percentage. In this respect a very gratifying change has since taken place, owing in a considerable degree to the influence exerted and the results obtained by the great public competitions, which have grown in importance every day since the first of them took place for the well-known roadbridge over the Rhine at Mayence in 1881[57]). "On that occasion", *Frentzen*[58]) says, "it became evident that the striking success of the design that proved victorious was based to a considerable extent on its mature architectural finish, the result being that in case of subsequent competitions the engineering firms, taking part in them, from the first secured the cooperation of architects in order to make sure of an artistic success as well." In this manner representatives of the two professions, hitherto acting separately, were brought together by common interest, and according to Frentzen, the advantage on the side of the arcithect above all consisted in this, "that by the exchange of views opportunity was given to him of becoming acquainted with the constructive conditions for the solution of the problems in question. This supposition, however, of a profitable exchange of artistic and constructive ideas can only be realised in case both parties work together from the very beginning; it appears necessary to lay particular stress on this, because it still happens occasionally that the principal constructive features of a design are being finally fixed by the engineer, before an architect is consulted for the purpose of putting the indispensable architectural cloak around it. That this mode of proceeding does not answer the purpose, is easily proved by the simple reflection that in case of larger bridges it is rather the impression produced by the structure as a whole, than by any architectural accessories not necessarily in organic relation to it, that determines its artistic value."

Fig. 63. Portal of the old Rhine Bridge at Kehl. 1860.

From his own point of view the writer can only express his entire agreement with this opinion. At the same time he can refer to the figures 62 and 64 to 71, as well as to many of the other illustrations, including those of the Appendix, representing the architectural features of some recent bridge portals and piers and of a few constructive details, in order to show some results of the joint work of architects and engineers.

Finally he cannot refrain from replying to an American critic, who has been recently assailing the architectural details of the Rhinebridge at Bonn (see fig. 69). The criticism referred to[58]) is essentially unjust, because it ridicules in

unmeasured terms some unimportant accessory parts of the portals, without even mentioning in a single word of acknowledgement the splendid impression undoubtedly produced by the structure as a whole (see fig. 105). Moreover, the details found fault with by the American critic, can for the most part only be found by specially looking out for them on the bridge. The writer does not wish to retaliate by criticising on his part the aesthetic features of the kind of iron structures usually put up by our American cousins, though this might not be without interest. But he is content to leave it to general judgement, whether a man desirous of criticising the engineering work of a foreign country, should not first try and obtain some insight into the special qualities characterising it.

16. THE QUESTIONS REGARDING THE SAFETY OF STRUCTURES. At first structures were built entirely without regard to theoretical considerations; they were created, following the demands of sheer necessity, by men of great inventive genius and practical ability (see page 8). Even the century of iron and railways was still rich in men of this type. When the first railway lines and engines, together with the first railway bridges, were to be taken in use, what doubts must have assailed these men before they could feel sure that everything they had planned worked safely and well! In case of iron bridges the important question of the *safety of the structure* at first could be solved only tentatively and by following experiments (see page 5). *Stephenson*, before building the Britannia Bridge, in 1842 constructed a model for experimental purposes in *one sixth* natural size, which was loaded up to breaking point. Similarly, before the old Dirschau bridge was built in 1850, *Lentze* at first intended to have a *trial* span made in full size. Being, however, told about a paper read in London by *Clark* on March 15th, 1880, concerning the completion of the Britannia Bridge, he thought he would be able to do without the trial, because, as he says, following the precedent of the Menai Bridge, the increase in the carrying capacity of the bridge, resulting from the rivetting up of the different parts of its superstructure (making it therefore continuous) would form sufficient surety for the correctness of the assumptions made for the calculation[60]).

How the different girder systems continued to develop in detail, particularly how in case of the older systems the narrow meshes of the lattice were by degrees replaced by larger ones, how finally the system of single division, with or without verticals, became gradually evolved out of the latter, all this will be described in detail later on (see 18 and 19). The development referred to proceeded simultaneously with the growth of theoretical knowledge and the tendency, resulting from it, of forming the outline as well as the general arrangement of the girder to suit theoretical requirements and economize material at the same time. On the other hand it was attempted to draw conclusions "a posteriori", concerning the correctness of the assumptions made, from the behaviour of finished structures under the action of loads, as well as from the presence and development of certain *deformations*. By this means the questions regarding the safety of structures, more particularly those relating to the best manner of fixing the *admissible strain*, as well as the allied problem of *secondary strains*, were brought nearer their scientific solution.

Fig. 64. Portal of the Isar Bridge at Munich. 1875.

German engineers at first contented themselves with accepting the figures for admissible strains as obtained from older English experiments and made known chiefly by Hodgkinson and Fairbairn (see page 5), in case of which the limits for tensional and compressive resistance were still fixed at different levels. While, however, England on the whole continued to adhere to this view, German designers gradually tried to put the assumptions referred to on a more scientific foundation. The merit of having gone forward in this matter is due to *Gerber*, now an "Oberbaurath" at Munich, whose work in Southern Germany has been of a character similar to that done by *Schwedler* in the North of Germany. He began by building the Isar Bridge at Gross-Hesselohe, and in 1858 took over the direction of the bridge department of Klett & Co.'s

Engine Works at Nuremberg, from which the present Nuremberg Bridge Company took its origin. In Gerber's publications concerning the Pauli bridge system[61]), dating from that period (1859), for the first time *special formulae for admissible strains* were made use of for calculating girder sections. Gerber in this instance fixes the admissible strain (in kilos per square centimetre) at $\sigma = \frac{E + 3P}{1600}$, where E is the strain of the bar in question resulting from the dead load, P that from the live load. In this formula the influence of the latter for the first time has been represented in a more scientific manner as regards its approximate proportion to that of the dead load. According to it Gerber permits a higher strain for a structure possessing a considerable dead weight, than in the case of a smaller one, where the fixed load is insignificant compared to the live load. The formula consequently takes into account the *influence of the impact* produced by rolling loads and fixes the upper strain limit for wrought iron, to be applied in case the live load is so small compared to the fixed weight, that it can be neglected, at 1600 kilos per square centimetre (10,16 tons per square inch), i. e. at the limit of elasticity of the material.

In consequence of the well-known experiments regarding the *repeated straining of iron bars*, carried out by *Wöhler*[62]) between 1859 and 1870, and continued by *Spangenberg*, the tendency referred to became further accentuated. Though it is undoubtedly true that with regard to these trials Wöhler was preceded by Fairbairn[63]), a fact pointed out first by *Mohr*[64]), the results of Wöhler's experiments at that time have had a revolutionizing effect on all branches of engineering in so far, as on the one hand they created a new basis for estimating the resistive qualities of iron and steel, and on the other furnished a means of forming scientific formulae for the admissible strain. Prompted by Wöhler's publications, Gerber at once tried to find a relation between the action of loads often repeated and that of fixed loads. The result was his well-known formula, published in 1871, for determining the admissible strain, adopted already in 1872

Fig. 65. Kaiser-Roadbridge at Bremen. Böttcher 1874.

for the calculation of structures on the Bavarian State Railways[65]). Quite recently, in 1894—96, Gerber has supplemented and extended the same subject still further[66]).

The utilisation of Wöhler's experiments for the scientific determination of the admissible strain has after Gerber, i. e. since 1871, been advanced chiefly by *Launhardt*[67]), *Schäffer*, *Winkler* and *Weyrauch*[68]). Launhardt takes into account merely the *change in the load*, not that in the *strain*, and ascertains the *working resistance* of a bar, meaning by this the strain, by which a bar is broken after an *infinitely great number of changes in the load*. The change in the direction of the strain, however, being, according to Wöhler, the most dangerous result of that in the load, Weyrauch supplemented Launhardt's formulae by introducing the so-called *vibrative resistance*, being that working resistance, in case of which, while the strain changes its direction, the limits of tension and compression become equal. The resulting *Launhardt-Weyrauch formula* supplies a simple means of fixing in a scientific manner the admissible strain for bars subjected to strains of opposite direction. *To-day*, it is true, the empirical figures occurring in the formula no longer appear altogether trustworthy, because sufficient data obtained from experiments with modern constructive materials, as used at present, are not at hand. This circumstance probably forms one of the reasons, why many designers — following Mohr's precedent[64]) — no longer regard as valid the formulae framed according to the principle explained above[69]). The directing board of the Prussian State Railways too, in their recent instruction concerning the calculation of iron bridges, does not take into account any formulae of this kind, but fixes the admissible strain independently for each class of structure, principally according to the size of the span and the manner, either direct or indirect, of transmitting the load. A simple method of this kind indeed offers many practical advantages, as long as the scientific formulae are not based on more reliable data than those to hand at present. The same opinion was also shared by Schwedler.

Fig. 66. Portal of the Roadbridge over the Northern Elbe at Hamburg. Hauers 1887.

An additional reason against the premature application of the scientific formulae referred to has recently presented itself. *Bauschinger*, the original chief manager of

the mechanical laboratory, forming part of the Munich technical college, has continued and added materially to Wöhler's experiments and as a result has been able to prove, that a *bar, as long as it is never being strained beyond the so-called limit of elasticity,* only gives way, after the change in the load has been repeated millions of times, a truth, which up to the present has not been seriously contested. Bauschinger's thesis, if applied to iron structures, which, in order to prevent permanent deformations, in none of their parts should be strained beyond the limit of elasticity, therefore signifies that such bars, as are *not strained alternately in opposite directions*, need not be calculated according to the formulae referred to. Consequently, in case of iron bridges merely the sections of the main bracing, the flanges of continuous girders, etc. would have to be determined by means of the method in question, while the rest of the sections could be fixed in each case according to empirical strain-figures, in a manner similar to that prescribed in the Prussian instruction mentioned above.

In close relation to the questions of admissible strains are those regarding the calculation of and, as far as possible, the doing away with the *secondary strains*, which for the most part are somewhat unaccessible to theoretical treatment. During the early stages of the development of structures secondary strains as a rule were ignored altogether. Girder calculations were carried out in as simple a manner as possible and based on the assumption of pin-connected nodes, as applied in case of the oldest iron girder systems (see page 15). When later on pin bridges did not prove successful, at any rate as far as Europe was concerned, designers soon replaced them by wholly rivetted bridge systems, without, however, relinquishing the convenient mode of calculation, based on the assumption of *frictionless pin connections* at the nodes, although many calculators had become more or less aware of its shortcomings. But the difficulties attending the calculative investigation of the errors committed proved to be so great that it cannot be wondered at, when the first calculation of this kind was only published late in the seventies, at a time, when the construction of braced girder bridges had been brought to a certain state of perfection (see tables I to IV). Almost at the same time *Winkler, Engesser, Asimont and Manderla* published the first works concerning secondary strains[70]. The most detailed investigations are to be found in the second part of Winkler's "Theorie der Brücken", where methods for determining the size of secondary strains as well as means of reducing them are given. Asimont in 1877 put the calculation of these strains as a prize-question to the Munich engineering faculty, whereupon Manderla in 1879 handed in an excellent solution making use of the hyperbolic functions[71]). A little earlier, however, Engesser had discovered a rather simpler, if only approximate method for the determination of secondary strains[72]).

Fig. 67. New Bridge over the Nogat at Marienburg. Jacobsthal 1891. With the old bridge in the background.

The instruments used since 1877 for *measuring strains*, particularly Fränkel's cleverly contrived extension-indicator[73]) to a great extent confirmed the results of the calculations referred to above, but at the same time raised grave apprehensious concerning the neglection of secondary strains, which up to that time had been the rule. Gerber consequently in many instances returned to pin-connected nodes, though it is now well known that these too, more particularly in the case of large spans (see page 17), may give rise to secondary strains of considerable magnitude, a fact first proved by Winkler and confirmed by Manderla by means of measurements at the Waltenhofen Bridge.

After a number of other prominent theorists, like *W. Ritter, Landsberg, Müller-Breslau, Mohr*[74]) and others have recently treated secondary strains, there is now a choice between different methods for their calculation. It is, however, only possible in a very few actual cases to make use of them for the design, because they are one and all far too laborious, in some cases too difficult, if not altogether inapplicable with any degree of accuracy. It must be added that secondary strains, if resulting from unavoidable errors, occurring during the erection of the structure at the works or in site, can only be included in the calculation by *estimating* their influence. In such cases, therefore, where at present secondary strains are really taken into account (which is not always done, but certainly ought to be done), it is usual either to reduce to some extent the admissible strain in the parts most subjected to them or else to estimate the secondary strains as a percentage of the original strains, i. e. those calculated on the assumption of frictionless pin-connections.

Only the masters of the profession can be expected to gain access to the often impassable field of secondary strains, in order to perfect their designs. In

this connection the author can bear witness to the great conscientiousness shown by at least one of them in this respect. After Schwedler had in 1888 handed over the preliminary designs of the iron superstructure for the new bridges over the Vistula at Dirschau and over the Nogat at Marienburg to the present writer in order to have the special designs commenced, one day early in 1889 he made the following remark concerning the girder system applied: "Though I can now see, I was wrong in choosing this system, I am not going to alter it again. Besides, during my last year's holydays I have been busy calculating the whole of the secondary strains of these bridges. Will you take the results? Here they are, but an addition of 25 per cent will do!" The writer was surprised and touched to hear, how the venerable senior of our profession had without the least regard to his already failing health, employed part of his well earned holydays to study minutely the details of his own designs in order to become acquainted with the manner, in which they would be affected by the secondary strains. This was the way he did his duty, truly a bright example to the youth of the profession!

Fig. 68. East portal of the Vistula Bridge at Fordon. Jacobsthal 1898.

The penetration and elucidation of the hitherto dark region of secondary strains by German scientists has had a far reaching influence on the further development of constructive details. After the facts discovered have become more generally known during the last ten years, the tendency has more and more been noticeable of reducing the secondary strains by means of a suitable choice of constructive sections, as well as by forming the bar connections at the nodes in a manner answering that purpose. This is being accomplished at present on the one hand by using symmetrical bar sections, with the material added also arranged symmetrically, joining them together at the nodes by means of duly centred bar- and rivet-connections, on the other hand by making use of hinged (or springy) bearings for the crossgirders and other parts of the platform at the nodes referred to, taking pains at the same time to make the transmission of the vertical as well as the horizontal loads statically determined, if possible, although the girder system itself may be a statically undetermined one. Later on (see paragraph 22) it will be shown, how these modern constructive principles have been realised in the case of important structures of recent date. If finally the great advance in the design of constructive details, due in a high degree to the deeper insight into the nature and action of secondary strains, is compared to the comparatively insignificant influence exerted in the same direction by the formulae concerning the admissible strains, as derived from Wöhler's experiments, the formulae referred to might appear to be of little practical value. This, however, would be a mistake. Though at present no doubt their field of application is a limited one and their value liable of being disputed, still the substance of the investigations described, as long as they are based on unexceptionable experiments, remains a thoroughly sound one, and it is to be hoped that together with many other questions regarding the life and safety of structures, that concerning admissible strains will find a thorougly satisfactory solution in the course of the twentieth century.

17. PERFECTION AND APPLICATION OF THE MATERIAL. The strong reciprocal action between railways and iron metallurgy, as described in the Introduction (see page 1), has exerted a far reaching influence on the development of the constructive material. Of the older building materials, timber and stone, still predominating at the time when the first railway bridges were being constructed, the former has soon fallen behind, while the latter even to-day is competing successfully with iron in many instances. Towards the middle of the century, when

braced girders were being perfected with the aid of theory, cast iron had already lost its importance for iron bridges and been gradually replaced by wrought iron. And after Bessemer's, Martin's and Thomas' inventions had revolutionized the metallurgy of the world during the last ten years of the century, even wrought iron had to give way to its stronger, more tenacious and uniform rival, *mild steel*. At the present time the basic varieties of the latter material are being generally preferred for structures of all kinds, and it is in the bulk production of these qualities that Germany greatly predominates, surpassing all other countries in a surprising degree (see page 7).

Cast iron, therefore, for some time continued in use in American bridge building, when it had been already discarded in Europe. It was as late as 1863 that the first American girder bridge was constructed entirely of wrought iron, compression members included. Even in this case, however, the girders were still provided with short cast iron joint-blocks at the nodes of the top flange. After that time cast iron slowly began to be discarded in America as well, while in Europe rivetted connections, precluding its use, had been generally adopted at a much earlier period, more particularly after the pin-connections of the Warren girders, forming the Trent

Fig. 69. East portal of the Roadbridge over the Rhine at Bonn*). Möhring 1898.

*) For further architectural details of this bridge see „Appendix".

Cast iron has the merit of being procurable in pieces and sections of any shape desired, a great advantage compared to wrought iron. It indeed proved of such moment as to make the deficiencies peculiar to cast iron appear in a milder light. In proportion, however, as during the development of braced girders the necessity of making the nodes of the structure secure by means of *rivetting* them up, was being more and more recognised, cast iron necessarily had to give way. In case of the older bridges, made either entirely of cast iron, or of cast and wrought iron combined, pin connections were being used throughout. Pin-connected nodes of the kind applied previously to the chains of suspension bridges, later on becoming typical of American bridge construction, are probably found for the first time at the Neville-Warren girders (see page 15).

Bridge at Newark, built in 1851, as well as those of the Crumlin Viaduct, built in 1853, had been found to be unreliable in consequence of their insufficient lateral stability. At the same time even Americans are now getting more and more used to structures rivetted up in the European manner. *Waddel*, for instance, in his paper entitled "De pontibus" (published in 1898) recommends pin-connected *or rivetted* girders for widths of 85 feet (about 25 metres) to 175 feet (52 metres), while in case of larger spans he, for reasons explained in page 16, still prefers the exclusive application of pin-trusses.

It was mentioned before that the difficulty of shaping wrought iron into any form desired greatly interfered with its speedy adoption for bridgebuilding purposes, above all in Germany, where the English inventions of puddling

and rolling were only tardily introduced (see page 5). The ordinary rail profile preceded all other sections. After people had learned to roll a rail, no further difficulty existed of producing other sections required in construction. Cast iron girders of the I, T, + and ⊔ sections had already been known to and calculated by *Navier* in his celebrated work[19]). Of wrought iron profiles, however, besides round, square and flat bars only window bars and angle irons were known in English metallurgy before 1830. To these were added at the time, when the first passenger railway was opened in 1830 between Manchester and Liverpool, the T iron and somewhat later the **Z** iron. The I section only appeared as late as 1849; it was introduced by *Zorès*, together with the ⊔ iron and (in 1852) the section of iron flooring, invented by him and called Zorès-iron on the Continent.

In Germany the first angle iron was rolled in 1831 and the first T iron in 1839 at Rasselstein near Neuwied. The I section was introduced as late as 1857 by the Phoenix Company, and in 1862 the well-known Burbach Works rolled the first **Z** irons for the iron bridges of the Ruhr and Sieg Railway, erected by the Cologne Engine Works at Bayenthal. It may be worth mentioning that of the so-called segmental sections, brought over from America, the quadrant iron was first made use of on the European Continent at the construction of a bridge crossing the Danube Canal in Vienna, built in 1868—70 by Ruppert.

The principal parts of bridge structures were (and are still) being formed of flat bars, plates and angle irons. Of the remaining sections the I iron has gained most in

Fig. 70. Portal of the Roadbridge over the Rhine at Worms. Hofmann 1899.

importance, since of late it can be rolled in considerable lengths and in profiles of comparatively great height, making it possible to use ordinary rolled joists independently as crossgirders and railbearers for bridges. The application of ⊤ irons (for stiffening webs and as bracing bars) and of Z- and flooring sections (for platforms) has remained a limited one, as far as the Continent is concerned. The ⊔ iron on the other hand has proved a good deal more convenient for use either as independent small girders, carrying railings, etc., or as bracing bars for cross frames and windbracings, finally as flanges for main girders of not too variable a section. Next to angle irons, I and ⊔ irons, therefore, are the principal parts used in construction, and their application would be a still more extended one, if the narrow flanges of many sections rolled on the Continent did not make it impossible to put in a good sized rivet.

Fig. 71. Portal of the Moselle Bridge at Trarbach. Möhring 1899.

As long as designers were restricted to the use of wrought iron, flat bars, angle irons and plates were particularly valued on account of the superior quality of their material. While the rolled sections referred to were of *uniform* tensional resistance and elongation *throughout*, the remaining profiles could be guaranteed to show the same figures only in case of the flanges, the webs being frequently of a somewhat inferior quality, and *transverse* tests being altogether out of question. This state of things has been greatly improved upon since the introduction of *mild steel;* for to-day (according to the German Standard Conditions) no longer any difference is made between flat bars, plates and other profiles of thicknesses varying between 7 and 28 millimetres ($^1/_4$ and $1^1/_8$ inch) as regards tensional resistance and elongation, longitudinal and transverse tests included. Mild steel, therefore, may be classed as a truly *homogeneous* material. Formerly people were

afraid of using wrought iron of great thickness, being in doubt as to the regularity of its texture. Even in the designs of the new Vistula Bridges at Dirschau and Marienburg all plates of one inch thickness for that reason were formed of two separate pieces of half an inch each, rivetted together. In case of mild steel nobody any longer thinks of dividing thick plates in this manner. On the contrary, in order to do away with superfluous areas exposed to the rust, it is recommended to form a structure of as few separate parts as possible. Beyond its uniformity of texture, mild steel possesses the further advantage of having a limit of elasticity at least 50 per cent higher than that of wrought iron, and a minimum *transverse stretch* of 17 per cent, compared to 3 per cent (rarely more) of the best kind of wrought iron, advantages, which have cleared a path for the new material, as soon as it had once been introduced, with surprising rapidity (see page 6).

The demands made at present concerning the quality of constructive materials, are regulated, as far as Germany is concerned, by the *Standard Conditions* for the delivery of iron structures, referred to above, the joint work of the societies of German architects, engineers and metallurgists. In consequence of the general adoption of these conditions, which moreover have served as a model to several foreign states, a number of controversial questions, dating back a considerable part of the century, have disappeared. We refer to the difficulty of classifying by comparison the different kinds of iron according to their degree of practical value or quality, and of obtaining some sort of official or universal sanction of the system of classification arrived at. From the very beginning opinions were at one, that above all the varying degrees of strength would have to serve as a scale for measuring the value of the different kinds of material. It is for this reason that the work referred to, concerning the fixing of uniform conditions, could only become successful, after by means of long continued experiments the disagreement regarding the most reliable way of making trials of strength, had become settled, in other words, after *the method of testing materials* had been turned into the right channel.

It has already been described in the Introduction (see page 5), how even at the beginning of the century people had been trying to find out the resistive qualities of constructive materials by means of experiments. England also in this matter took the lead at first, particularly by setting up during the fifties the first public testing works for iron and steel, followed somewhat later by the French institution, named "Service des recherches statistiques". The well known testing works established and directed by *Kirkaldy* have proved of historical importance. Kirkaldy has made breaking tests by traction in a systematic manner with more than a thousand different sorts of iron and steel, varying in quality and shape in every imaginable way; not content with testing the *strength*, he in each case noted the *ductility* of the material, measuring the latter by the *elongation* of the piece and its *contraction at the breaking point.* But in Germany too there were already in existence at that time a number of efficient and reliable testing machines, being the property of a few larger iron works or railway companies. In 1852 the Royal Building Commission of the Bavarian State Railways at von Pauli's suggestion ordered a machine for testing the iron tie rods for some girders of the Howe type from the Engine Works of Klett & Co. at Nuremberg — the present Nuremberg Company — and this machine, designed by *Werder,* the manager of the works, became soon known on account of its perfect working. It was constructed for loads up to 100 tons and made it possible for the first time to strain bars of a size, as they are required for practical use, up to breaking point, at the same time furnishing the figures of strength with a degree of accuracy hitherto unattainable. Already on the occasion of the building of the Isar Bridge at Grosshesselohe, which was opened for railway traffic in autumn 1857, i. e. simultaneously with the old Vistula Bridge at Dirschau (see table I), the iron to be used was tested by the Werder-machine not only with regard to its breaking strength, but the whole of the flat bars to be strained in tension were tried separately up to 1140 Kilos per square centimetre (7,25 tons per square inch), while the sledge-hammer was being applied to them. The same method was further extended in case of the railway bridge over the Rhine at Mayence towards the end of the fifties (see table I). In 1866 Culmann procured the second Werder-machine for the Zürich technical college; in 1871, 1873, 1875 and 1879 the colleges of Munich, Vienna, Pest and Berlin followed with their orders. At the same time the first German *public* testing works were established at Munich and Berlin.

By the introduction of the Werder-machine as well as by *Wöhler's* highly important experiments, dating from 1867—1870 and referred to on page 43, the testing of constructive materials in Germany was advanced by a great step. Among the men who took a prominent part in this advance, above all *Bauschinger* is to be named, the former manager of the mechanical laboratory of the Munich technical college. Bauschinger has considerably extended Wöhler's experiments (see page 44 and 45) and in addition called and presided over many meetings of experts for the purpose of deciding about "uniform testing methods for building and constructive materials", between 1882 and 1893. After his death *Tetmajer* took over Bauschinger's work and continued it in the spirit of the departed. Thus in September 1895 the *"International union for testing constructive materials"* was founded at Zürich, from which during its further course of development, in 1896 the *"German union for testing constructive materials"* was branched off through the exertions of prominent German specialists, like *von Bach, von Leibbrand* and *Martens.* The society mentioned last is intended to do the same kind of work in Germany, which the International union performs generally, viz. chiefly to bring about agreements regarding uniform testing methods for ascertaining the technically important qualities of building materials. There is occasion to hope that the inducement offered by the proceedings of the societies referred to will tend to keep the German "Standard Conditions" on a level to continue to serve as a model to other countries.

18. THE FIRST IRON RAILWAY BRIDGES IN GERMANY. The extension of railways having been of decisive influence on the perfection of the material as well as on the development of iron bridge construction, it appears advisable to precede our further remarks by a few

historical observations regarding the first iron railway bridges. It was already explained in the Introduction (see page 5), why in the course of Central European railway construction the first iron bridges of importance were built only towards the middle of the century, i. e. fully twenty years later than in England. During this interval the German and Austrian railways still continued to construct most of their bridges of timber and stone, later on replacing them by iron structures; on a few of the older lines, for instance on the Leipzig and Dresden railway, this happened as late as the seventies.

As far as known, the first iron bridges to be found in Germany were some cast iron ones, built between 1840 and 1845 on the Baden Railways. They chiefly consisted of girders of from 3 to 5 metres (10 to 16 feet) span, showing a **T** or **⊔** section, to which longitudinal sleepers were bolted. In case of larger spans trapezium-and arched trusses of different systems, as well as arches, were used. One of the structures worth mentioning among these is the cast iron archbridge, carrying two lines of railway, built in 1843 to 1845 over the Kinzig near Offenburg, with five spans of 12,7 metres (41′ 7½″) each, which in 1851 fell in owing to its piers becoming underwashed. The longitudinal sleepers, carrying the rails on this bridge, are supported by six arched girders of a **T** section, carved out at the spandrels and consisting each of three separate flanged pieces, bolted together as well as to the abutment. As usual in these older cases of railway bridges, the transverse connections were extremely inadequate, consisting merely of a few adjustable tie-rods, scarcely any cross-bracing being provided. This is the more surprising, as there were already in existence on the Continent a good many roadbridges of exemplary design, which could have served as models, as for instance the Havel Bridge at Potsdam, finished in 1825, the seven arched girders of which in each of its eight spans were rigidly held together by means of four transverse members and three cross frames, or the Pont des Arts, dating from 1803, and the Caroussel Bridge, built in 1836, at Paris, both of these early French works being still in existence. Cast iron strut-frames, lying below the rail level, have been constructed first, as far as known, in 1846—1848 for the smaller Havel Bridge at Potsdam and the Ehle Bridge at Magdeburg on the Berlin - Potsdam - Magdeburg line of railway (see fig. 72).

Fig. 72. Strut frame of the Railway Bridge over the Elbe near Hegrothsberge. 1846—1848. (Dimensions in millimetres.)

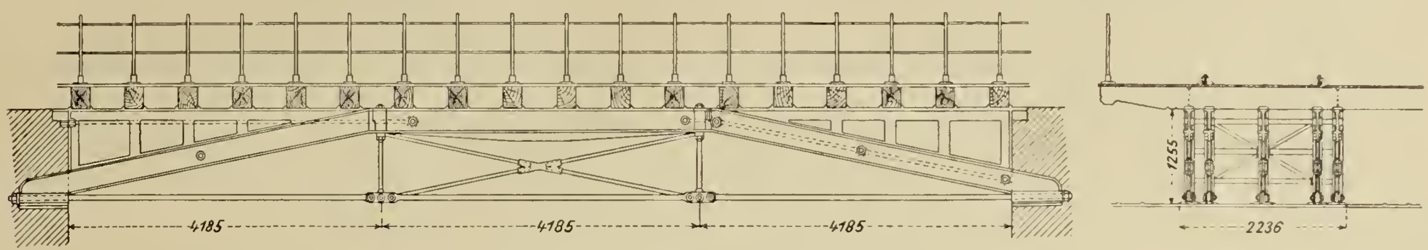


Fig. 73. Railway Bridge over the Neisse at Guben. Henz 1846.

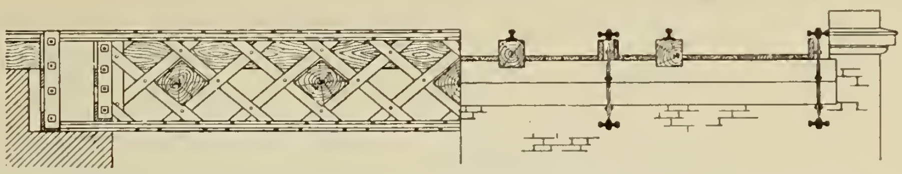


Fig. 74. Lattice Bridge over the Wupper adjoining the Rittershausen railway station. 1847. (Dimensions in millimetres.)

Fig. 74 a.

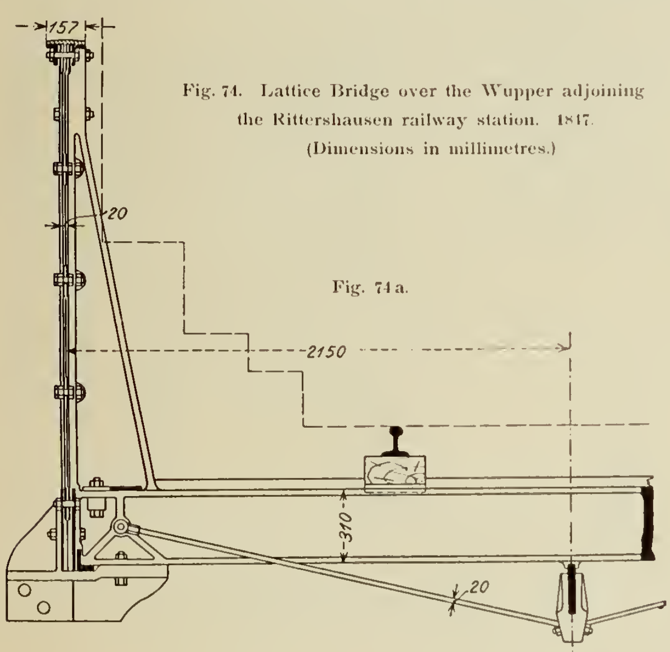


Fig. 74 b. View.

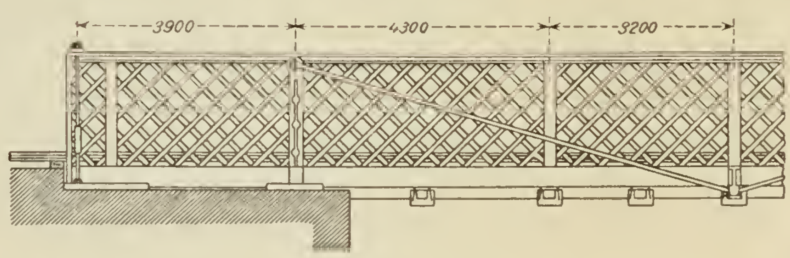
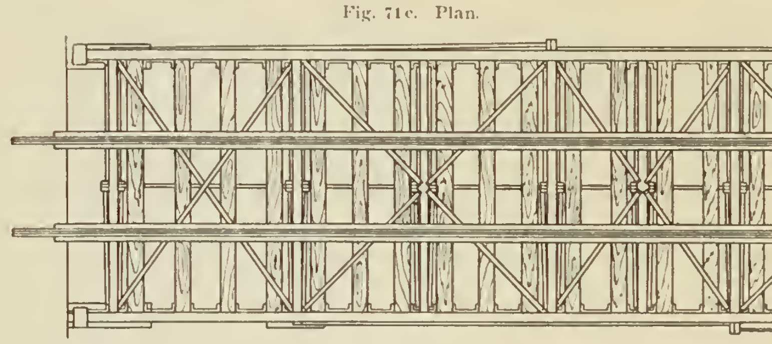


Fig. 74 c. Plan.



Wrought iron railway bridges only appeared in Germany as late as the middle of the fourties, first probably on the Niederschlesisch - Märkische and the Berlin and Potsdam Railways. In 1846 *Henz*, following American models (see page 15), introduced the lattice girder with parallel flanges, the latter being formed of two rails rivetted together and connected by a system of flat bars, entwined and rivetted together at the points of intersection (see fig. 73). This trellis-like lattice work, however, was soon abandoned.

Already a year later (in 1847) a bridge was built over the Wupper*), adjoining the Barmen—Rittershausen railway station on the Elberfeld and Witten line, the lattice girders of which consisted of flanges formed, like those of plategirders, of a plate and two angle irons, and two groups of flat bars, intersecting without being entwined (see fig. 74). This bridge, being provided with cast iron cross frames, in 1874 has been replaced by a plategirder bridge. Of

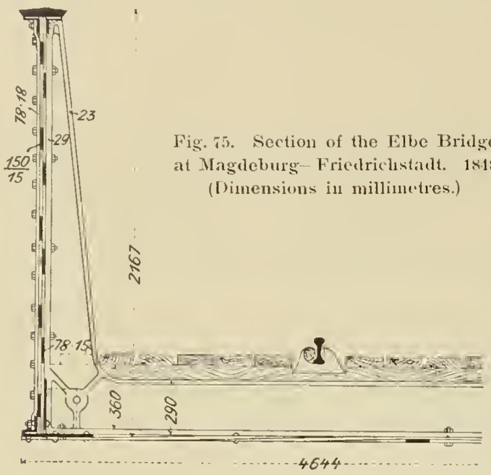


Fig. 75. Section of the Elbe Bridge at Magdeburg—Friedrichstadt. 1848. (Dimensions in millimetres.)

similar construction to the Wupper Bridge just described were the lattice bridges built in 1848 over the Old Elbe, the Mittelelbe and the Stromelbe at Magdeburg with spans up to 21,3 metres (69′ 11″). A few of the structures mentioned last still continue in use to-day, notwithstanding their cast iron cross frames, because up to the present they have been kept in a perfect state of preservation, no trace of rust being observable, and because no express trains pass over them, the bridges in question only accomodating a few goods trains between Magdeburg and Magdeburg—Friedrichstadt (see fig. 75). It remains to be mentioned that the *Saale Bridge at Grizehna* (see fig. 76 and 77), built in 1848, was also provided with **T** flanges, made entirely of wrought iron, while in case of the *Ruhr Bridge near Altstaden**), which is a little older, the top plate still consisted of cast iron.

Fig. 78. Fishgirder of the Magdeburg—Halberstadt Railway. 1847.

Fig. 78a. View.

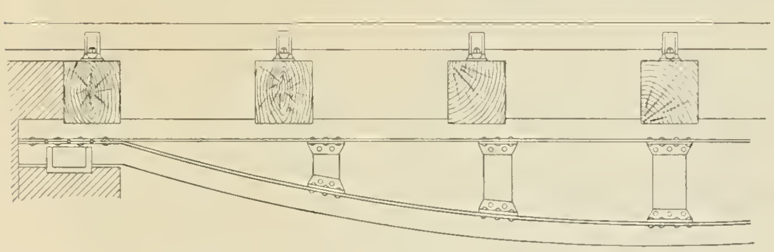
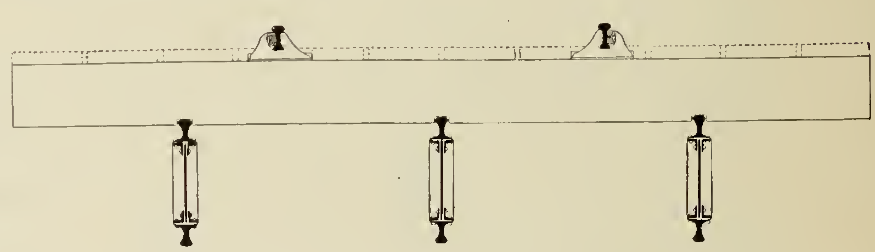


Fig. 78b. Section.



The first wrought iron bridges on the railway lines referred to above were from about 1846 in case of very short spans provided with so-called *rail girders*, consisting of two ordinary rails rivetted together, or with *fishbelly girders*, also formed of two rails, the lower of which was curved and stiffened by means of cast iron blocks or wrought iron stays (see fig. 78). In figures 79 to 81 three further examples of older designs for small spans are shown: a lattice bridge of the Ruhr and Sieg Railway, built in 1857—1861, with the timber sleepers passing through the lattice work and two bridges with *arched railgirders* on the Thuringian Railway, built in 1847, and on the Dortmund and Soest line, dating from 1855. The mode of construction in each case is clear from the drawings and proves how people learned to make shift at a time when theory was still in its infancy. The whole of these smaller structures,

Fig. 76—77. Saale Bridge at Grizehna. 1848.

Fig. 76a. Section.

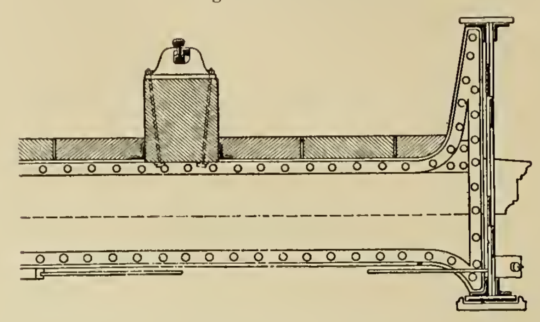


Fig. 76b. Details of the windbracing.

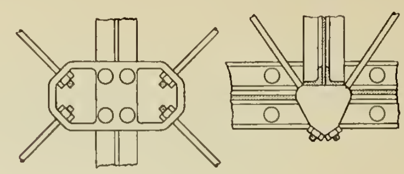
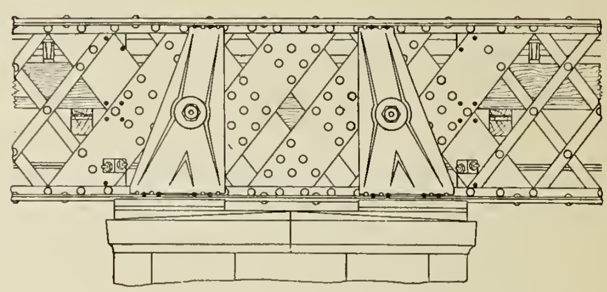


Fig. 77. Bearing on the intermediate piers.



originally made of iron, as well as the old timber bridges, some decades after their construction have been gradually replaced by more modern systems. For this purpose plategirders were almost exclusively made use of, which as far as German railways are concerned, have been first adopted early in the fifties by the Hanoverian Railway, the Rhenish, Westphalian and other lines subsequently introducing them on their several systems.

The design of *plategirders* has been attended to with particular care in Germany. When about 1850 the iron bridges for the Southern and Western Railways of Hanover had to be designed, first of all a series of comparative tests of plategirders and lattice girders under varying loads was instituted[75]). Navier's recommendation and calculation of the **I** section, as well as the results of Hodgkinson's experiments, according to which the tensional resistance of wrought iron had proved greater than its compressive strength, were at that period still relied on. It was therefor tried to ascertain on the one hand, which way of distributing the material over the section of plategirders

*) Made by Johann Caspar Harkort of Harkorten, the present Harkort Company at Duisburg.

would prove most advantageous, and on the other hand, whether, while adhering to Navier's assumptions, the thin web of a plate girder or the bracing bars of a lattice girder would offer the greatest resistance, the consumption of material being the same in each case. For this purpose a number of bridge models had been constructed in one third natural size, and the final results of the tests proved the superiority of the web plate compared to lattice work of equal weight.

In the course of the further development of plategirders the necessity of stiffening the web soon raised doubts regarding the correctness of the calculation according to Navier's theory. Schwedler in 1851 pronounced it necessary to regard and calculate stiffened plategirders of considerable height as braced girders with verticals, while Culmann in 1852 proposed to calculate even the smallest girder webs by substituting for them diagonal strips, re-

Fig. 79. Braced girder bridge on the Ruhr—Sieg Railway. 1857. (Dimensions in millimetres.)

Fig. 79a. View.

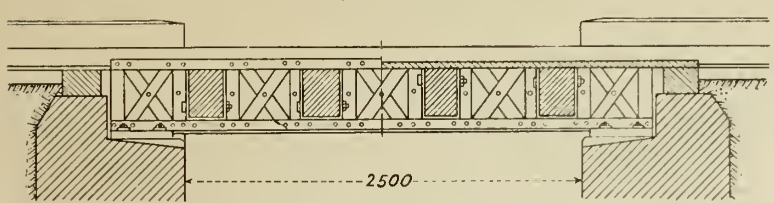


Fig. 79b. Section.

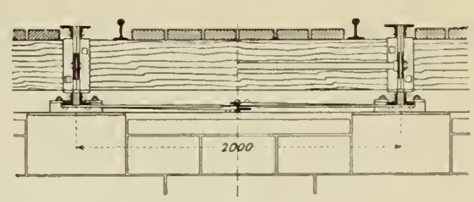


Fig. 79c. Girder sections.

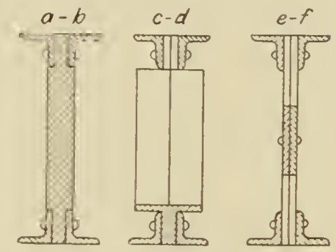


Fig. 79d. Plan.

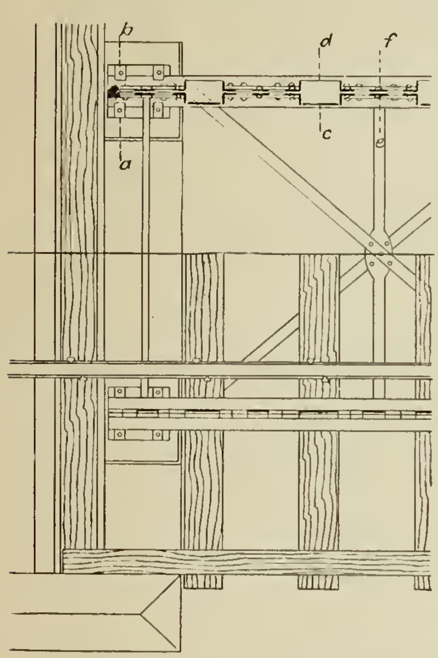


Fig. 80. Arched rail girder of the Thuringian Railway. 1847. (Dimensions in metres.)

Fig. 80a. View.

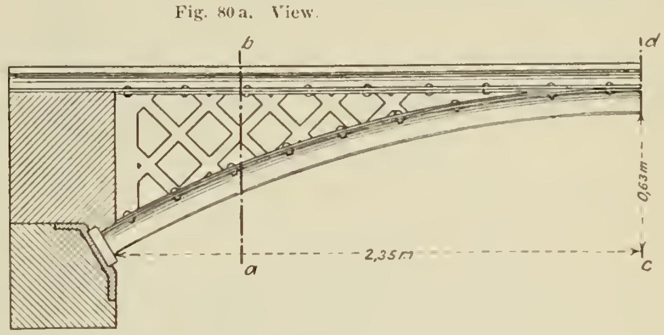
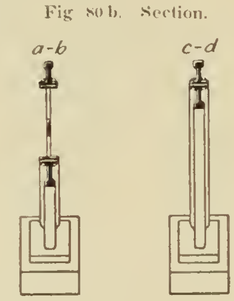


Fig. 80b. Section.



presenting bracing bars. Other theorists were busy determining the *shearing strains* in the web. *Köpcke*[76]) in 1858 first represented them graphically, stating at the same time that in case of sections with both large moments and shearing forces acting upon them, the greatest strain may occur no longer at the edges, but in the interior of the section. The first complete calculation of plategirders including that of the stresses occurring at each point of their section was published in 1857—63 by *Laissle* and *Schübler*[77]).

In the meantime the construction of lattice girders too had been perfected, with the result that plategirders were subsequently only made use of for smaller spans. The plate girders of the Yssel Bridge near Westerwoort (see page 19) with spans of 50 metres (164 feet), of the Spey Bridge on the Inverness and Aberdeen line with 70 metres (230 feet) and of the Garonne Bridge near Langon with 74,4 metres (244 feet) span, built in 1855, have remained isolated examples. At present, as far as Europe is concerned, plategirders as a rule are applied only to spans up to about 50 or 65 feet. In America[37]), on the other hand, they are (according to Waddell) used generally for spans up to 85 feet. As we know by experience to-day that, the web being stiffened in the usual manner, the current thicknesses of the webplate from at least 8 millimetres ($^5/_{16}$ inch) upward, are quite sufficient for taking the bending as well as the shearing strains, produced by the load, with perfect safety, the simplest formulae are naturally preferred for calculation. The more exact calculation of plategirders presents some difficulty only in such cases, where being used as *crossgirders* or *railbearers*, they form part of the bridge platform, and in consequence of being firmly fixed to the maingirders or else to cross- and windbracings, have to undergo deformations of a peculiar kind. This point will be referred to again (see 22).

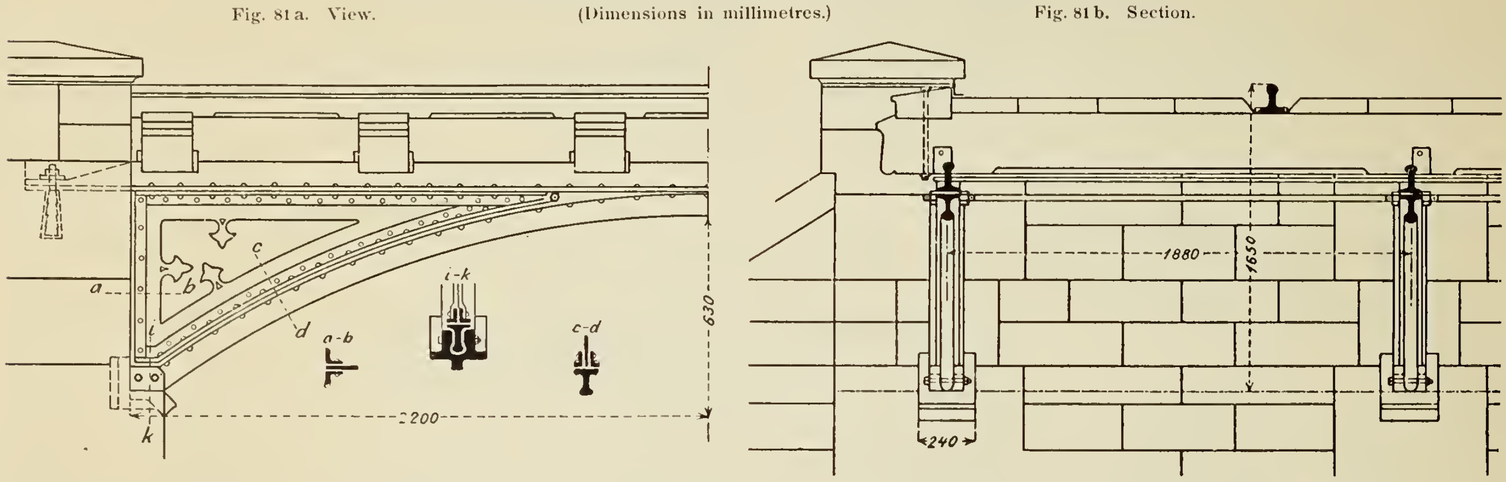
19. BRACED GIRDER BRIDGES. Simultaneously with the introduction of plategirders, braced girders were being developed, the oldest German excamples of which have already been represented in figures 73 to 77. The greatest sensation, however, was caused at the time by the erection of the old bridges over the Vistula at Dirschau (see fig. 16) and over the Nogat at Marienburg, the preparations for which were begun, when the Britannia Bridge (see fig. 15) had not yet been opened, when therefore no girder bridges exceeding about 200 feet span were in existence. At first it was intended to build a suspension bridge at Dirschau, which in order to diminish the excessive vibration peculiar to them at that time, and consequently to make it possible to pass single locomotives, if not entire railway trains, over the bridge, was to consist of five large spans of 158 metres (518 feet) each. For it was known by experience that chainbridges of very wide span vibrate a good deal less than smaller ones. Somewhat later, however, when *Lentze*, the designer of the bridges, together with *Mellin*, the chief of the building department.

and the menager of the engine shops, erected specially at the Dirschau site (see also 23), went to England to study the Britannia Bridge, then in course of construction, he at once recognized the momentous import of Stephenson's great work. He accordingly abandoned the suspension bridge design and decided to build a more rigid structure, without however imitating the tubular form of the Britannia Bridge. Lentze finally made up his mind to choose a lattice girder system. Being still in doubt whether the carrying capacity of a structure surpassing the Britannia Bridge by about 4,4 metres (14′ 4½″) in span, would come fully up to the assumptions made in his calculation, he originally (as was already mentioned on page 42) intended to erect a *trial span* of full size, which was to be tested at the Dirschau site (in 1851) under varying loads.

Thus the Dirschau and Marienburg lattice bridges came to be constructed with a finish of workmanship, which even to-day excites the admiration of experts. Theory and practice on this occasion united to create something as nearly perfect as possible. The girders of these bridges in the design of their principal parts show a considerable advance on the ordinary lattice bridges of that period, which like the Neisse Bridge at Guben, the Ruhr Bridge at Altstaden and the Saale Bridge at Grizehna, etc., were all provided with flanges and lattice bars of uniform section throughout. The thickness as well as the other dimensions of the bracing bars in this case on the contrary were fixed conforming to their strain, ascertained according to Schwedler's and Culmann's theories. In addition the lattice was stiffened by means of angle iron verticals, which, corresponding to the variation in the shearing force, were put closer together near the abutments than at the centre of the girder (see fig. 16). The Dirschau Bridge was provided with open cellular flanges, formed of vertical and horizontal plates with angle irons, further with braced cross-girders and braced transverse frames above the platform. Moreover, there are *three* windbracings, one below the bottom flange, the two others above and below the top flange. The Marienburg Bridge, on the other hand, has no cellular flanges; in that case the horizontal and vertical flange plates have been extended by steps in a peculiar manner from one girder to the other, forming a roof and a windbracing at the same time.

Fig. 81. Arched rail girder on the Dortmund and Soest line of railway. 1855.

Fig. 81a. View. (Dimensions in millimetres.) Fig. 81b. Section.



To *Lentze* is due the great merit of having first proved the possibility, always doubted up to that time, of spanning our great northern rivers by rigid bridges. Taking into account the comparatively imperfect scientific and technical resources of his time, we cannot help admiring the courage of this eminent engineer, who with these insufficient means at his disposal did not hesitate to take upon himself the responsibility for the successful accomplishment of the great work. Lentze also knew how to attach to himself a permanent staff of numerous able assistants (see also 23). Among these above all *Schinz* is to be named, who in his capacity as chief draughtsman to the building department, for five years devoted his whole strength to the great work in hand. The calculation and working out of the detailed design was mainly done by him; in addition he had to take care of the organisation of the work, including engines and apparatus used for erecting the iron superstructure. The early death of this highly intellectual man was marked by truly tragic circumstances. His ingenious calculations were finished; one third of the structure had been erected; he had already determined by calculation the exact curve to be assumed by the girder under its own weight, as soon as the scaffolding had been removed, and in great suspense was waiting for his statement to be confirmed. At that moment, his strength having become undermined by continued overexertion and worry, he suddenly succumbed to an apoplectic stroke on October 8, 1855. It was not granted to him to live to see the triumph of his finished work. A few days later the girders were hanging free from pier to pier, exactly following the curve he had assigned to them beforehand[67]).

Schinz was buried in the cemetery at Dirschau, in view of the structure, the successful completion of which to a great extent was due to his exertions. A monument of polished granite, erected by the government, marks his resting place. Its inscriptions in gold letters read as follows:

Front:
Rudolph Eduard Schinz
Engineer
Born at Zürich
April 17, 1812
Died at Dirschau
October 8, 1855.
Back:
In memory of the meritorious work
of their cooperator
in the building of the Vistula and
Nogat Bridges.
The Royal Building Department.

Table I*).

Remarkable German Girder Bridges, built between 1850 and 1860.

Number	Time of construction	Description of bridge	*Designer* and builders	Spans Number	Width in metres	Width in feet	Girder system
1	1850—57	Old Bridges 1) over the Vistula at Dirschau. 2) over the Nogat at Marienburg, Berlin and Königsberg railway.	*Lentze.* Built by the State.	6 2	130,9 101,4	430 333	Open cellular flanges. Stiffened lattice web of close division. Girders continuous over two spans. See fig. 15, 63 and 68.
2	1852	Roadbridge over the Enz at Pforzheim.	Benkiser Brothers, Pforzheim.	1 1	31,0 28,0	102 92	Flat bar lattice webs of close division.
3	1853	Günz Bridge at Günzburg on the Bavarian Maximilian Railway, Augsburg and Ulm line.	*Pauli.* Klett & Co., Nuremberg.	1 1	12,3 10,3	40 34	See fig. 82 and 83. Forerunner of the Pauli girder.
4	1853	Roadbridge over the Neckar at Untertürkheim.	Esslingen Engine Works.	3	29,0	95	First iron bridge in Württemberg. Flat bar lattice of close division. Wrought or cast iron top flange.
5	1854	Railway Bridge over the Mulde near Buckau, Chemnitz-Aue line.	Königin Marienhütte at Cainsdorf near Zwickau.	3	36,0	118	First iron bridge in Saxony. Flat bar lattice webs (continuous) of close division.
6	1854	Wiesen Bridge near Basle. Baden State Railways.	Benkiser Brothers, Pforzheim.	1	44,0	144	Lattice webs of close division.
7	1855	Lippe Bridge on the Cologne and Minden Railway.	—	2 2	27,2 17,7	89 58	Flat bar lattice of close division.
8	1855—59	Railway- and Roadbridge over the Rhine between Cologne and Deutz, Cologne and Minden Railway.	*Lohse.* Built by the Köln-Mindener Railway Co.	4	99,0	325	Lattice girders, as described.
9	1856	Oder Bridge near Oswitz on the Upper Silesian Railway.	—	1	31,4	103	Flat bar lattice webs of close division. Including a swingbridge, 9,4 metres (30′ 9″) wide.
10	1856	Bridges over the Ocker on the Brunswick Southern Railway.	—	3 1 1	27,4 14,3 11,7	90 47 38	Flat bar lattice webs of close division.
11	1857	Isar Bridge at Grosshesselohe, Munich and Salzburg line of railway.	*Pauli, Werder.* Klett & Co., Nuremberg.	2	52,0	171	See fig. 26 and description.
12	1857	Rhine Bridge near Mayence, carrying the first track of the Hessian Ludwig Railway.	*Pauli, Werder, Gerber.* Nuremberg Company.	4	105,2	345	Second track built in 1870. Besides 24 spans of 15,8 to 35,0 metres (51′ 9″ to 114′ 10″) Pauli girders.
13	1857	Flackensee Bridge near Erkner, Berlin and Frankfort-on-Oder Railway.	*Schwedler, Malberg.*	1	25,7	84	Parallel-girder with verticals and crossed diagonals in all panels. + section of the bars.
14	1857—58	Moselle Bridge near Coblenz, Linksrheinische Railway.	*Hartwich.* Harkort Company.	4	41,4	136	Quadruple bracing of a T-section, stiffened by verticals.
15	1858	Railway Bridge over the Ilmenau near Bienenbüttel, Lüneburg and Uelzen line.	*von Kaven.*	4	16,6	54	First German bridge with verticals and crossed diagonal ties.
16	1858	Bridge over the Kinzig at Offenburg, Baden Railways.	*von Ruppert.*	1	62,8	206	Flat bar lattice of close division, stiffened by parallel rails.
17	1858—60	Old Railway Bridge over the Rhine between Kehl and Strassburg, Baden State Railways.	*Keller.* Benkiser Brothers, Pforzheim.	3	60,0	197	Lattice girders, as described, continuous over the three central river piers. 4 additional spans of 26 metres (85′ 4″ each with swing bridges. See fig. 63.
18	1858—60	Railway- and Roadbridge over the Nahe at Bingen, Linksrheinische Railway.	*Hartwich.* Harkort Company.	3	34,5	113	Quadruple bracing of a T-section, stiffened by verticals.
19	1859	Kinzig Bridge at Kehl, Baden Railways.	*Keller.*	1 2	35,4 32,4	116 106	Flat bar lattice webs of close division.
20	1859—60	Rhine Bridge on the Waldshut and Coblenz line, Baden State Railways.	*Gerwig.* Benkiser Brothers, Pforzheim.	1 2	55,0 37,2	180 122	Flat bar lattice webs of close division. Continuous over 3 spans.

*) In tables I to VI the names printed in *italics* are those of the designers. In a number of cases, however, the latter could not be identified.

In the preceding table, containing the whole of the braced girder bridges of Germany, dating from the sixth decade, which are in any way remarkable, the Vistula and Nogat Bridges are immediately followed by a bridge of the Bavarian Maximilian Railway, the girders of which can be regarded as forerunners of the Pauli girder type.

The Bridge over the Günz at Günzburg on the Augsburg and Ulm railway, has been designed by von Pauli and erected in 1853 by the Engine Works of Klett & Co. at Nuremberg*). Its construction did not prove successful, chiefly on account of the peculiar design of its timber platform, strengthened by iron, as shown in figures 82 and 83**). One day in 1854 when a train was passing the bridge, the top flanges of one of the spans buckled out laterally, though the bridge did not fall in at once. The iron superstructure of both spans was consequently removed, altered in various ways at the Nuremberg works and in May 1855 put up again and taken over by the railway authorities. In April 1856 strong longitudinal timber sleepers were put under the rails in order to further increase the lateral stability of the top flange, and the structure subsequently held out till 1868, when it had finally to be pulled down and replaced by a plategirder bridge.

Fig. 82 and 83. Günz Bridge near Günzburg on the Augsburg and Ulm railway. 1853.

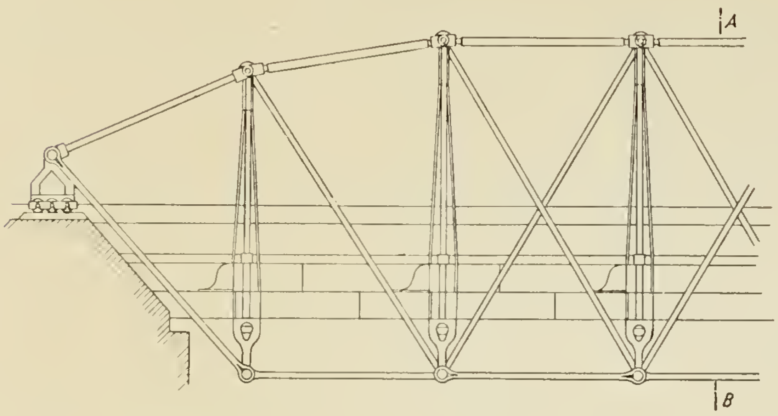


Fig. 82 a. View.

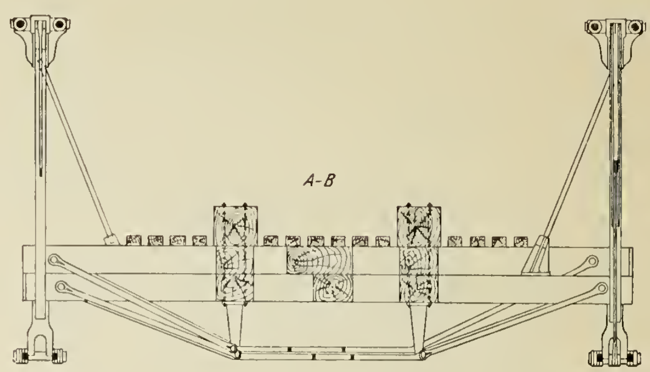


Fig. 82 b. Section.

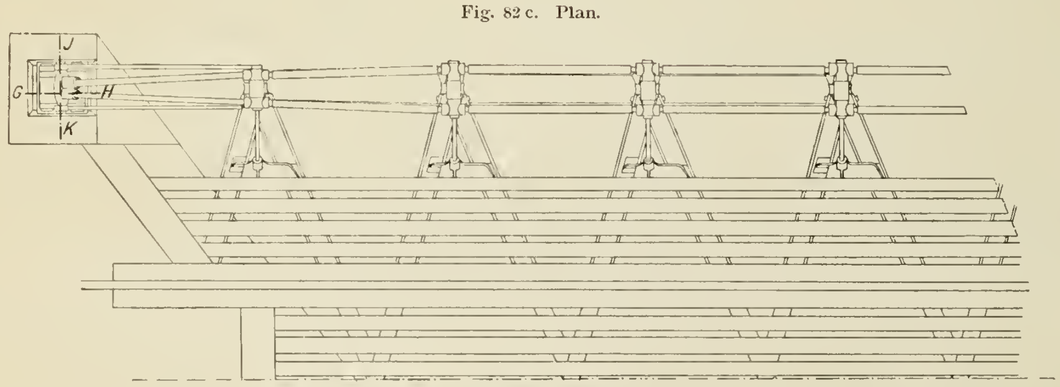


Fig. 82 c. Plan.

By contemplating the constructive details of the Günz Bridge, as represented in detail in fig. 83, and comparing them to such of recent design, the state of bridgebuilding at that period will be better understood than by reading any descriptions. Above all the *absence of all rolled sections* strikes the eye, round and square bars being the only ones used, and all connections being consequently effected by means of bolts and screws with cast iron sockets. There is no counter diagonal in the second panel (see fig. 82a); besides, no windbracing between the flanges is provided, the triangular arrangement of the crosssleepers, forming part of the platform (see fig. 82c), being hardly satisfactory as a substitute. The longitudinal sleepers have only been added on a subsequent occasion, as was mentioned before. From all this it will be clear that according to our present views the transverse stiffness of the top flange was decidedly inadequate.

The second of von Pauli's early works, viz. the *Bridge over the Isar at Grosshesselohe* on the Munich, Rosenheim and Salzburg line, erected in 1857*) (see fig. 26), compared to the Günz Bridge, shows a number of important improvements. Built at the same time as the Flackensee Bridge on the Niederschlesisch—Märkische Railway, designed by Schwedler, like that structure it contains some constructive details, at once well thought out and of surprising simplicity. The platform, being on top, is supported by four main girders with box-shaped upper flanges, which, being open at top and bottom, are formed of four angle irons, while the bottom flange consists of flat bars connected by means of conical bolts. The verticals passing through the open top flange are formed of angle irons, held together by bolts, one metre (3′ 3″) apart. The main bracing bars are connected to the cornerplates by means of pins. The crossgirders, provided with brackets on each side, as well as the railbearers, are designed as braced girders, the former showing a triangular bar system, the latter verticals and crossed diagonals. Between the top flanges there is a windbracing consisting of angle iron posts and crossed flat bar diagonals, while the bottom flanges are connected by means of tie-rods, which together with vertical crossframes, formed of flat bars, assist in stiffening the bridge laterally. In addition a secondary windbracing is provided between the top flanges of the

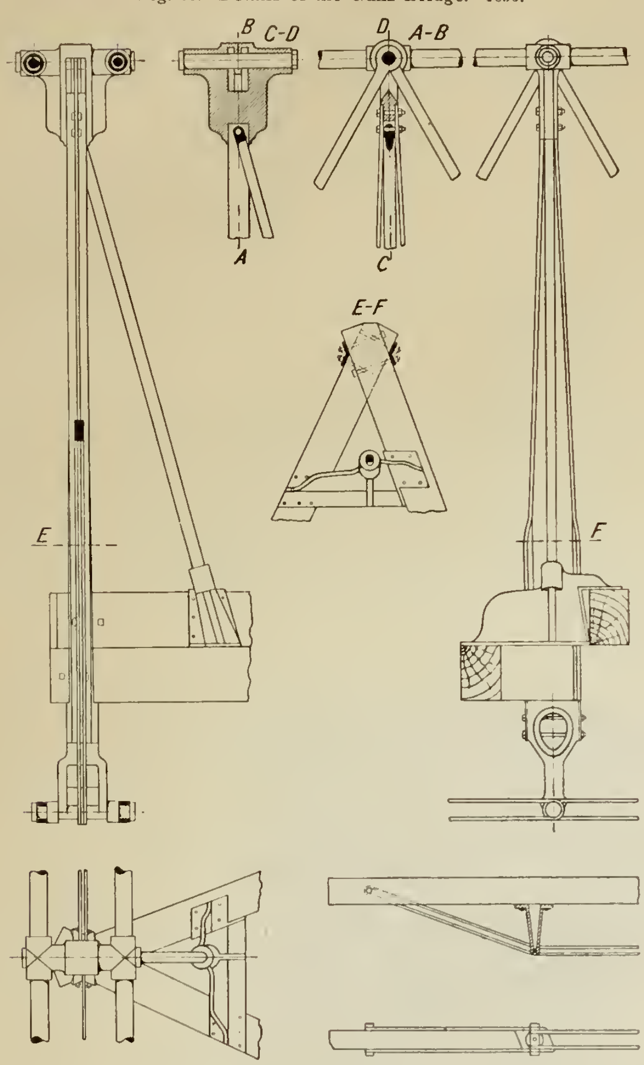
*) The present Nuremberg Engine Works, Ld.

**) According to information supplied by the Royal Board of the Bavarian State Railways.

*) By Klett & Co., the present Nuremberg Engine Works.

platform girders. Taking further into account the *hinged bearings,* which were a new feature at the time, the construction of the Isar Bridge, compared to the failure of the Günz Bridge, must be pronounced a success. If we

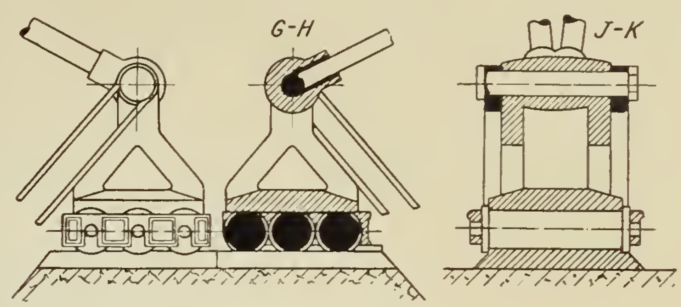
Fig. 83. Details of the Günz Bridge. 1853.



remember that besides the lattice bridges over the Ruhr at Altstaden, over the Saale at Grizehna (see fig. 76 and 77) and over the Vistula at Dirschau (see fig. 16) no further remarkable German railway bridges were in existence at that time, the iron superstructure of the Isar Bridge, in the design of which, besides von Pauli, the Nuremberg Works referred to took a prominent part, on the whole must be regarded as an important advance in the development of braced structures. The care bestowed on the testing and general manipulation of the material on the part of the builders deserves particular acknowledgement. Already at the erection of the Günz Bridge all wrought iron parts of the structure were tested by traction and compression on the Werder—machine (see page 50), the tension bars being heavily hammered during the process. The same was done in case of the Isar Bridge up to a tension of 1140 kilos per square centimetre (7,24 tons per square inch). Moreover, the operations of cleansing the iron before putting on the paint, of subsequently grounding and painting it were already accomplished in a manner similar to that in general use at present.

The iron superstructure of the Isar Bridge is still being used to carry a single line of railway and on the whole has remained unaltered. Merely the main diagonals have been artificially strained of late in order to prevent

Fig. 83 a. Bearing of the Günz Bridge (Sections from fig. 82 c).



any buckling under the action of live loads (see page 16). In addition the longitudinal timber sleepers have been replaced by iron railbearers, carrying timber crosssleepers.

Up to the sixties the Pauli girder system has been repeatedly applied to smaller bridges on the Bavarian Railways; besides the Nuremberg Works have constructed several roadbridges on this system, for instance that built in 1866 over the Lech at Schongau (see fig. 84) with three spans of 27 metres (89 feet) each, provided with an iron flooring of segmental plates. For some further examples see table II (Nrs 2, 6 and 32). After 1858, an additional number of lattice and plategirder bridges, as well as strutframes made of rails, were erected. The last and most important application of the Pauli system is found in the railway bridge crossing the Rhine near Mayence, constructed in 1857—70 for the Hessian Ludwig Railway (comp. Table I, Nr 12).

The lattice girder bridges enumerated in table I have been chiefly designed in imitation of the old Vistula Bridge, though the bridges at Cologne and Kehl contain a few in-

Fig. 84. Roadbridge over the Lech at Schongau. 1866.

dependent improvements. The Cologne Bridge consists of two separate structures for road and railway respectively, the maingirders of the railway bridge having *double* lattice webs, connected by means of braced members rivetted to both of them, while those of the roadbridge are provided with a *single* one only, stiffened by verticals formed of plates and angle irons. The flanges of the maingirders are **T** shaped like those of the Saale Bridge at Grizehna (see fig. 76). The Kehl Bridge has *three* maingirders with single lattice webs, carrying two lines of railway, the footpaths on each side of the bridge being supported by brackets rivetted to the lattice work of the outer girders. Both of these old Rhine Bridges are provided with full-webbed crossgirders, a new feature at their time of construction, the older bridges in every case showing braced crossgirders. The Kehl Bridge, moreover, has an upper windbracing, formed of angle irons, the posts of which by means of gusset plates and angle iron stays are rivetted to the maingirder verticals.

Among the remaining structures enumerated in table I, the Kinzig Bridge, designed by *von Ruppert,* the *Flackensee Bridge,* by *Schwedler,* and the *Ilmenau Bridge,* by *von Kaven,* are the more important ones. Ruppert's structure, erected in place of an arch, which in 1851 broke down (see page 51), in no respect can be regarded as an improvement on earlier examples, though some novel details to be found in it at that time attracted a good deal of attention[78]). The use of flanges and flat bar bracing, showing a *uniform* section throughout the bridge, in connection with the fact that the latter was *not stiffened by any verticals,* can even be regarded as a retrograde step, compared to the lattice bridges referred to before. But the most doubtful feature of the structure is found in the design of its crossgirders, which consist of trapezium strut-frames, made of Vignoles rails and provided with horizontal tie-rods below the platform, to take the thrust. In case of the *Lattice Bridges over the Eipel and Gran* in Upper Hungary, built at the same time as the Kinzig Bridge, Ruppert formed one set of the lattice bars, which in these instances are further apart, of so-called bridge rails able to resist compression, a mode of construction certainly to be commended, though it could not be called new at the time, Schwedler having made use of it in an even more rational manner at the Flackensee Bridge.

The main bracing of the Flackensee Bridge consists of verticals and crossed diagonals, of the kind, which *Winkler* used to calculate by ignoring the verticals altogether (see page 16). Like the Isar Bridge, described above, the Flackensee Bridge contains a number of remarkable new details. Among these chiefly the *cruciform section* of the bracing bars and the flanges is to be mentioned, further the design of the railbearers, which are continuous over the crossgirders, finally the rational and lucid connections and joints between all parts of the structure by means of plates and angle irons. The only feature of the bridge, that may be taken objection to, is the windbracing, which by the application of keys at the nodes for the purpose of straining the bars, suggests American models. In his calculations Schwedler has ascertained the actual strains in the different parts of the structure (in kilos per square centimetre) as follows: Flanges 520, bracing bars in compression 430, in tension 580, crossgirders 560, railbearers 300 (being respectively 3,30 — 2,72 — 3,68 — 3,56 and 1,91 tons per square inch). At the same time he had taken great care to make the compression members safe against buckling, and to strengthen all parts of the platform sufficiently to resist the impact of the live load.

Fig. 85. Danube Bridge near Ingolstadt. 1869.

It is only with the construction of the *Ilmenau Bridge* that the lattice web stiffened by verticals was finally given up in favour of the system of bracing, consisting of verticals and crossed diagonal ties, though at first the latter could not compete for some time with the multiple lattice without verticals, which was being extensively used (see page 16). The *Moselle Bridge at Coblenz* (see Nr 14) and the *Nahe Bridge at Bingen* (see Nr 18), both with a quadruple system of stiffened diagonals, have found numerous imitations.

In Table II, containing a further series of remarkable bridges dating from the sixties, a number of smaller spans have been omitted, which show a bracing of *double* division without verticals, the first example of this type being Number 3. Among these there are many bridges on Gerber's system. The diagonal bracing of *triple* division without verticals is only found in case Nr 1, while the triple system with verticals is represented by Nrs 4 and 25, the *double* by Nrs 5, 10, 21 and 24. Lattice webs of close division (12, 13, 18) are slowly falling back, until finally the type showing single verticals and diagonals with *counter diagonals* added, begins to rule the market (19, 20, 26, 29).

Table II.

Remarkable German Girder Bridges of a span exceeding 35 metres (115 feet), built between 1860 and 1870.

Number	Time of construction	Description of bridge.	*Designer* and builders	Spans Number	Width in metres	Width in feet	Girder system
1	1861	Inn Bridge near Passau, Bavarian Eastern Railway.	Nuremberg Company.	1	90,4	297	Double web of triple diagonal bracing without verticals.
2	1863	Roadbridges over the Danube at Kelheim. at Deggendorf.	*Gerber.* Nuremberg Company.	 5 8	 38,0 38,0	 125 125	Pauli girders. Platform on top, consisting of timber planking on longitudinal timber beams.
3	1863—64	Bridge at Oberlahnstein, on the Coblenz and Oberlahnstein railway.	*Hartwich.* Harkort Company.	1 2	42,4 32,0	139 105	First German bridge with double webs of double diagonal bracing, without verticals. Flat bar flanges of the smaller spans.][shaped flanges.
4	1863—64	Bridge over the Old Rhine near Griethausen, Cleve and Zevenaar railway.	*Hartwich.* Harkort Company.	1 and 20 small ones	100,4	329	Triple set of diagonals with verticals; the so-called Mohnié system. + shaped flanges.
5	1864	Weser Bridge at Corvey, Altenbeken and Holzminden railway.	*Schwedler.* Gutehoffnungs Works.	4	58,3	191	Schwedler girders with double set of diagonals and verticals, the end strut of one of the bracing systems being omitted. Double flanges, being a combination of the + and T section.
6	1864	Aurach Bridge near Euskirchen, Würzburg and Nuremberg line.	*Pauli.* Nuremberg Company.	3	37,0	121	Pauli girders.
7	1865	Danube Bridge near Scheer, on the Danube line, Württemberg State Railways.	Royal Railway Building Commission, Esslingen Engine Works.	2	38,0	125	Semiparabolic girders. Besides two spans of 19 metres (62 feet) each with parabolic girders. Situated in a curve of 458 metres (24 chains) radius.
8	1865	Kinzig Bridge near Steinach. Baden State Railways.	Benkiser Brothers, Pforzheim.	1	62,0	203	Parabolic girders with crossed diagonals.
9	1865	Tauber Bridge at Gerlachsheim. Odenwald Railway.	*Keller.*	1 2	36,0 18,0	118 59	Semiparabolic girders.
10	1865—67	Railway- and Roadbridge over the Rhine between Ludwigshafen and Mannheim.	Benkiser Brothers, Pforzheim.	3	89,0	292	Parallel-girders. Double set of diagonals with verticals; bracing not rivetted up at the points of intersection.
11	1865—68	Bridge over the Weser at Bremen, on the Bremen and Oldenburg line.	*Berg.*	3	48,2	158	Bowstring girders. With a swingbridge of two spans.
12	1865—73	Bridges on the Danube line of the Württemberg State Railways. 1) at Sigmaringen } over the 2) at Rechtenstein } Danube 3) over the Lauchert at Sigmaringendorf.	Royal Railway Building Commission, Esslingen Engine Works.	 1 2 1 1	 60,0 39,3 } 25,8 } 45,3	 197 129 } 85 } 149	T bar lattice webs of close division, with parallel flanges.
13	1866	Bridge over the Kocher Valley near Tullau. Württemberg State Railways.	Royal Railway Building Commission, Esslingen Engine Works.	3	50,2	165	Double lattice webs of close division. 4 continuous girders for 2 lines of railway.
14	1866	Neckar Bridge at Neckarhausen. Württemberg State Railways.	Benkiser Brothers, Pforzheim.	3	32,2	106	Braced girders with parallel flanges.
15	1866	Tauber Bridge near Gerlachsheim. Baden State Railways.	Benkiser Brothers, Pforzheim.	1 2	37,0 19,0	121 62	Parabolic girders with crossed diagonals.
16	1866—67	Parnitz Bridge near Stettin on the Berlin and Stettin railway.	*Schwedler.* Cologne Engine Works, Ltd., at Bayenthal.	2	37,7	124	Schwedler girders. Besides a swingbridge with two clear spans of 12,6 metres (41′ 4″) each.
17	1867—68	Oder Bridge near Stettin, Berlin and Stettin railway.	*Schwedler.* Gutehoffnungs Works.	1 1 1	39,5 52,7 44,2	130 173 145	Sewedler girders. With a swingbridge of the same dimensions as Nr. 16.
18	1867	Bridge over the Bühlerthal near Vellberg. Württemberg State Railways.	Royal Railway Building Commission. Esslingen Engine Works.	3	62,0	203	Double lattice webs of close division. 4 continuous girders for 2 lines of railway.

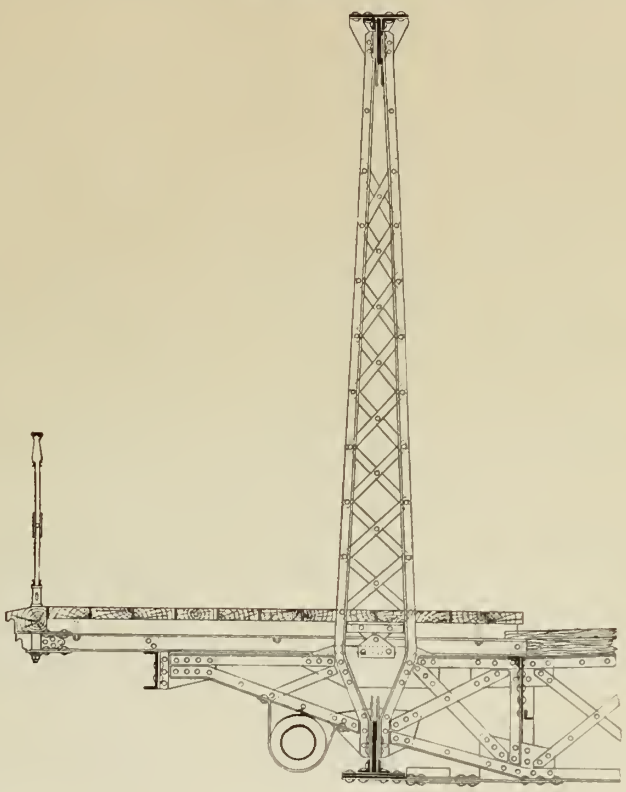
Number	Time of construction	Description of bridge	*Designer* and builders	Spans Number	Width in metres	Width in feet	Girder system
19	1867	Roadbridge over the Main at Hassfurt.	*Gerber.* Nuremberg Company.	1 2	37,9 23,9	124 75	First Gerber-girder. Singlo diagonals and verticals. Timber platform. See fig. 36.
20	1867	Sophien Bridge over the Regnitz at Bamberg.	The same.	1 2	42,8 26,6	140 87	Gerber-girder. Single diagonals and verticals. Ballast on flooring plates.
21	1867	Elbe Bridge near Meissen on the Borsdorf-Meissen railway.	Harkort Company.	3	51,0	167	Semiparabolic girders. Double diagonal system with verticals.
22	1867—68	Elbe Bridge at Hämerten, on the Berlin-Lehrte railway.	*Schwedler.* Harkort Company.	5 4 8	63,4 37,7 31,5	208 124 103	Schwedler girders. Verticals with single set of diagonals in the smaller, double set in the larger spans. Besides a swing-bridge with two spans of 13 metres (42′ 8″) each.
23	1868	Tauber Bridges: 1) at Gamburg. 2) at Bronbach.	Benkiser Brothers, Pforzheim.	 1 2 1 2	 34,8 27,6 30,6 24,0	 114 91 100 79	Braced girders with parallel flanges.
24	1868—69	Danube Bridge near Ingolstadt, Munich and Gunzenhausen railway.	*Gerber.* Nuremberg Company.	3	53,9	177	Girders with parallel flanges and double set of diagonals with verticals. Single webs. + flanges of the main-girders of peculior design. See fig. 85.
25	1868—70	King William-Railway Bridge over the Rhine near Hamm, Düsseldorf and Neuss line.	*Pichier.* Harkort Company.	4	105,9	347	Semiparabolic girders. Triple set of diagonals with verticals. Swingbridge with two spans of 13,4 metres (44 feet) each and 15 masonry arches of 18,8 metres (61′ 9″) each.
26	1869	Ruhr Bridge at Hattingen, Bergisch-Märkische Railway.	Gutehoffnungs Works.	4	40,8	134	Schwedler girders. Verticals and single set of diagonals.
27	1869	Elbe Bridge near Magdeburg on the Potsdam and Magdeburg line.	*Schwedler.*	5 10	63,0 31,5	207 103	Like No. 22.
28	1869	Roadbridge over the Brahe at Bromberg.	*Schwedler.*	1	36,7	120	Open Schwedler girders, with verticals and flanges stiffened in a peculior manner (see fig. 86).
29	1869	Isar Bridge near Munich. Munich and Braunau Railway.	*Gerber.* Nuremberg Company.	3	50,2	165	Girders with parallel flanges, verticals and crossed diagonals.
30	1869	Tauber Bridge near Mergentheim. Württemberg State Railways.	Benkiser Brothers, Pforzheim.	1 2	35,6 15,0	117 49	Braced girders with parallel flanges.
31	1869	Nagold Bridges of the Württemberg Black Forest line.	Esslingen Engine Works.	9	from 47,0 to 63,0	from 154 to 207	Ditto.
32	1869—70	Roadbridge over the Wertach at Kaufbeuren.	*Gerber.* Nuremberg Company.	1	49,0	161	Pauli girders. Ballast on corrugated iron.

The most prominent bridge designer of the period between 1850 and 1870, just described, is undoubtedly found in *Schwedler* (1823 to 1894), who for some dozens of years almost ruled supreme in this branch of engineering, his influence being felt over a wide area extending far beyond the frontiers of Germany. Having won the Cologne prize (see page 12) when still young, and published his first important theoretical work about the same time[79]), Schwedler from the moment, when in 1858 he entered the Prussian Ministry of Public Works, up to his resignation in 1891 was the originator of almost every remarkable iron structure erected by the Prussian Building Departments. Undoubtedly he was a designer and a theorist of the very first rank, being moreover of an eminently practical turn of mind. The passages from his first scientific work, already cited on page 39, are characteristic of his way of thinking. The present writer, who was fortunate enough to be in official communication with Schwedler for several years, from his personal intercourse with him still remembers a good many of his striking sayings, proving beyond doubt that throughout his life he acted strictly according to the principles set forth there, allowing for instance a good deal of licence to his assistants in working out designs, as soon as he had recognised their abilities. In a high degree he possessed the faculty of judging constructive details as to their practical value at first sight (see page 39). Unsuitable or faulty details were simply brushed aside with the laconic remark: "That will never do!", without as much

as looking at the accompanying calculations. When on a similar occasion the writer had tried his hand at a somewhat unusual construction and submitted it to him, Schwedler declined it with the remark: "It would be a very good thing, if it could be done, and we have in fact been trying to do it before, but really, it won't do!" A list of Schwedler's literary works, treating each and every branch of engineering, is to be found at the end of Sarrazin's obituary[80]), while hundreds of structures, scattered over all parts of the world, testify to his untiring activity as a designer.

The first German bowstring girder, the *Brahe Bridge* near Czersk on the Bromberg and Thorn line, with two openings of 25,4 metres (83 feet) each, was designed by Schwedler, who also introduced the symmetrical -|- and H shaped flanges, as well as those of a combined -|- and T section (see Nrs 5, 22 and 27, table II). A very remarkable bridge of the Schwedler type is that built over the Brahe at Bromberg, the flanges and verticals of which are stiffened in a very rational manner, shown in fig. 86, in order to increase the lateral stability of the top flange, there being no upper windbracing. Finally Schwedler's rivet arrangements, proposed and explained by him in a remarkable theoretical treatise[79]), as well as his well designed swingbridges, deserve to be mentioned.

Fig. 86. Section of the Roadbridge over the Brahe at Bromberg. Schwedler 1869.



arrangement of the rivets, and that at a time, when secondary strains were scarcely yet thought of. This is conclusively proved by the details of his design of the Danube Bridge at Gross-Prüfening (see Nr 12, table III and fig. 88). In his capacity as manager of the South German Bridge Works at Gustavsburg Gerber at an early date (1867 to 1868) recognised the importance of limiting the rivetting work in site as much as possible, in order to reduce the cost of erection and at the same time increase the strength of the structure. For this reason he introduced the so-called *concentrated* joint, which, in contrast to the *divided* joint, allows the rivetting up at the works of large ready-made pieces, only to be joined together at the nodes in site. Schwedler, too, gave preference to the concentrated joints, though in case of smaller bridges he occasionally made use of the divided joint also, particularly for flanges of single or double cruciform section, formed of a combination of angle irons.

Finally it may be mentioned that Gerber, when building the railway bridge over the Rhine at Mayence (see Nr 12, table I), already made use of *iron girders* for the erection of the river spans, further that on the same occasion he approached the questions concerning the calculation of rivet connections by making experiments with regard to

Fig. 87. Roadbridge over the Danube at Vilshofen. Gerber 1872.

In the South of Germany *Gerber*, whose important work has already been repeatedly referred to, was in the first rank of designers. The tables I and II as well as the following table III contain a great number of iron bridges, designed or originated by him. Among these particular renown has been won by the *cantilever* structures, on the novel design of which Gerber in 1866 took out a Bavarian patent[81]). It was already mentioned on page 22, that the principle of these girders was suggested to him by Ruppert's design of a bridge over the Bosporus.

In all his designs Gerber laid particular stress on the centric connection of all bars, as well as a symmetrical arrangement of the rivets [cont.] the upsetting pressure of turned bolts. In his paper about these experiments[82]) Gerber incidentally gives a formula used by him since 1859 (erection of the Isar Bridge at Grosshesselohe) for calculating the resistance of bars against *buckling*. By means of this formula he determines the force to be applied transversely at the centre of a strut sufficient to prevent its buckling out. As a result of some more experiments he applied a different formula of similar construction later on, which was published in a note treating the well known catastrophe of the Mönchenstein Bridge[83]).

Table III.

Remarkable German Girder Bridges of a span exceeding 50 metres (164 feet), built between 1870 and 1880.

Number	Time of construction	Description of bridge	Designer and builders	Spans Number	Width in metres	Width in feet	Girder system
1	1870	Roadbridge over the Danube at Sigmaringen.	Esslingen Works.	2	54,2	178	Schwedler girders.
2	1871	Danube Bridge at Mariaort, Regensburg and Nuremberg railway.	*Buchler.*	3	63,0	207	Quadruple set of diagonals, no verticals. ╥ flanges.
3	1871	Inn Bridge at Simbach, Munich and Simbach line.	Nuremberg Co.	1 5	60,4 59,2	198 194	Girders with parallel flanges, verticals and crossed diagonal ties.
4	1871—72	Railway- and Roadbridge over the Vistula near Thorn.	*Schwedler.* Gutehoffnungs Works, Prange (Magdeburg).	5 1 1	97,3 39,0 36,0	319 128 118	Semiparabolic girders with verticals and double set of diagonals, and parallel-girders with crossed diagonals in all panels.
5	1871—72	Elbe Bridge at Dömitz, Wittenberge and Buchholz railway.	*Häseler.* Harkort Co.	3 7	67,8 34,0	222 112	Schwedler girders with verticals and double set of diagonals.
6	1871—74	Rhine Bridge of the Venlo-Hamburg railway line near Wesel. 2000 metres (6562 feet) long.	*Funk, Mackensen.* Harkort and Backhaus.	4 6	98,3 19,2	322 63	Semiparabolic girders. Verticals and triple set of diagonals. Besides 97 masonry arches.
7	1872	Lech Bridge at Kaufering, Munich and Buchloe line.	Nuremberg Co.	2	55,7	183	Parallel-girders with quadruple diagonal system without verticals. + shaped bracing bars and flanges.
8	1872	Roadbridge over the Danube at Vilshofen.	*Gerber.* Nuremberg Co.	1 4	64,5 51,6	212 169	Gerber girders. See fig. 87.
9	1872	Weser Bridge at Dreye, Osnabrück and Bremen line.	Harkort Co.	3 15	60,7 27,2	199 89	Semiparabolic girders with verticals and double set of diagonals.
10	1872—73	Bridges over the Laber Valley: 1. at Beratzhausen, 2. at Deiningen, Nuremberg and Regensburg line.	Nuremberg Co.	3 4 1	58,7 58,6 } 71,7 }	193 192 } 235 }	Parallel-girders. Triple set of diagonals, no verticals.
11	1872—75	Memel Bridge near Tilsit, Tilsit and Memel line, with the Uszlenkis and Kurmerszeries Bridge.	*Schwedler, Ramm.* Union Works.	5 2 10	96,7 13,5 68,0	317 44 223	See fig. 25. Truncated elliptical girders with crossed diagonals, no verticals. Intermediate flange.
12	1873	Danube Bridge at Gross-Prüfening, Ingolstadt and Regensburg railway.	*Gerber.* Nuremberg Co.	3	78,0	256	The ends of the girders show a parabolic outline.
13	1873	Danube Bridge at Poikam, Ingolstadt and Regensburg railway.	Nuremberg Co.	4	52,0	170	Parallel-girders with crossed diagonals, no verticals.
14	1873—74	Viaduct of the Palatinate Railways over the Zeller Valley near Marnheim.	Benkiser Brothers, Pforzheim.	2 2	60,0 50,0	197 164	Iron piers with cast iron columas. Parallel-girders with quadruple set of diagonals and stays, no verticals.
15	1874	Kaiser-Roadbridge at Bremen.	*Schwedler.* Gutehoffnungs Works.	2 2 1	50,1 26,3 43,3	164 86 142	Parallel-girders with crossed diagonals in each panel. See fig. 65.
16	1874	Road- and Railway Bridge over the Elbe at Niederwartha, Berlin and Dresden line.	*Häseler.* Gutehoffnungs Works.	3 13	62,0 21,0	203 69	Semiparabolic girders with double, and parallel-girders with single bracing system.
17	1874—75	Road- and Railway Bridge over the Elbe at Riesa, Leipzig and Dresden line.	*Fränkel.* Harkort Co.	2 6 1 3	97,6 } 30,6 } 97,6 } 30,6 }	320 } 100 } 320 } 100 }	Semiparabolic girders with verticals and triple set of diagonals in the main spans. Fell in March 3, 1876, the piers being underwashed.
18	1874—75	Bridge over the Zeglinstrom near Stettin, Berlin and Stettin railway.	Harkort Co.	1	92,0	302	Semiparabolic girders with verticals and double set of diagonals. Tide spans: parabolic girders.
19	1875—76	1. Remsthal Bridge near Neustadt-Waiblingen. 2. Kocherthal Bridge. Württemberg State Railway.	Esslingen Works. „ „	4 1	56,0 60,0	184 197	Parallel-girders with quadruple diagonal system, no verticals. Length 240 metres (787 feet), Height 45 metres (148 feet).
20	1875—76	Rhine Bridge of the Palatinate Railways near Germersheim.	*Basler, Trau.* Benkiser Brothers.	3	90,0	295	Parabolic girders with verticals and double set of diagonals.

Number	Time of construction	Description of bridge	*Designer* and builders	Spans Number	Spans Width in metres	Spans Width in feet	Girder system
21	1875—76	Bridges over the Inn: 1. near Königswart, 2. near Jettenbach. Plattling and Rosenheim railway.	Nuremberg Co.	3 1 1 3	68,0 28,0 20,0 52,0	223 92 66 171	Like Nr. 13.
22	1876	King Albert-Bridge over the Elbe at Schandau. Road- and Railway Bridge.	Königin Marienhütte, Cainsdorf.	1 2	80,0 50,0	263 164	Semiparabolic girders with verticals and double set of diagonals.
23	1876	Danube Bridges: 1. at Deggendorf, Eisenstein and Plattling line, 2. at Donauwörth, Ingolstadt and Neuoffingen line.	Nuremberg Co.	6 4	60,0 60,0	197 197	Like Nr. 13.
24	1876	Ohe Valley Bridge, Deggendorf, Eisenstein and Pilsen railway.	Nuremberg Co.	1	76,0	249	Parabolic girders. Crossed diagonals, no verticals.
25	1876—77	Elbe Bridge at Barby on the Berlin and Güsten line, with a Tide Bridge at Flötz.	Gutehoffnungs Works.	6 10 6	65,5 33,8 25,2	215 111 83	Like Nr. 16.
26	1876—79	Vistula Bridge near Graudenz, Thorn and Marienburg line.	Union Works.	11	97,3	319	Semiparabolic girders with verticals and double set of diagonals. See fig. 89. Like Nr. 4.
27	1877	The Rhine Bridges: 1. at Altbreisach, Imperial Railways of Alsace-Lorraine. 2. at Neuenburg. 3. at Hüningen. Baden State Railways.	Gutehoffnungs Works.	3 4 3 2	72,0 28,0 72,0 36,0	236 92 236 118	Parallel-girders with verticals and double set of diagonals.
28	1877	Neckar Bridge at Marbach. Württemberg State Railways.	Benkiser Brothers.	5	68,0	223	Parallel-girders with triple set of diagonals, stiffened by verticals.
29	1877	Danube Bridge at Sigmaringen. Württemberg State Railways.	Esslingen Works.	1 1	66,0 33,0	217 108	Schwedler girders with single diagonals and verticals (without counter diagonals).
30	1877	Weser Bridge near Wehrden, Ottbergen and Northeim line.	*Geck.* Harkort Co.	1 10	89,7 32,5	294 107	Semiparabolic girders. Crossed diagonals with intermediate flange, no verticals. Braced parallel-girders.
31	1877—78	Railway- and Roadbridge over the Elbe at Riesa, Dresden and Leipzig railway.	*Köpcke.* Königin Marienhütte, Cainsdorf.	3 1	100,0 43,4	328 142	Parabolic girders. The strains in the bottom flange, due to dead load, have been artificially done away with by means of a balance-weight and levers.
32	1877—78	Elbe Bridge at Lauenburg, Büchen and Lüneburg line.	*Grüttefien.*	3 3	103,0 51,0	338 167	With swingbridge. Like Nr. 4. Tide spans: Parallel-girders.
33	1878	Ruhr Bridge at Steele, Rhenish Railway.	Gutehoffnungs Works.	1 1 10	52,0 31,9 17,3	171 105 57	Parallel-girders with verticals and double set of diagonals (large spans), and single set (small spans).
34	1878	Neckar Bridge at Neckargemünd. Baden State Railways.	Benkiser Brothers.	1 2	76,0 56,0	249 184	Parallel-girders with verticals and crossed diagonals in each panel.
35	1878	1. Kübelbachthal Bridge and Stockerbachthal Bridge on the Gäubahn. 2. Ettenbachthal Bridge near Freudenstadt.	Esslingen Works.	3 2 1 2	60,0 49,5 60,0 49,5	197 162 197 192	Continuous parallel-girders. Quadruple set of diagonals without verticals. 280 metres (919 feet) long, 48 m (158 feet) high. Length 160 metres (525 feet); height 31 metres (102 feet).
36	1878—79	Road- and Railway Bridge over the Moselle at Bullay, Coblenz and Trier line.	*Hilf. Altenloh.* Harkort Co.	1 5 1	88,6 33,5 11,8	291 110 39	Parallel-girders with intermediate flange, quadruple set of diagonals, no verticals. Railway on top of girders, road below.
37	1879	Bridge over the Ill and the Rhine and Rhône Canal at Strassburg. Imperial Railways.	Esslingen Works.	2	50,5	166	Semiparabolic girders with verticals and double set of diagonals.
38	1879—80	Neckar Bridge of the Hessian Ludwig Railway at Mannheim.	Benkiser Brothers.	1 2	76,0 56,0	249 184	Like Nr. 34.
39	1880	Bridge over the Senfeld Lake at Schweinfurt.	Esslingen Works.	2	52,0	171	Schwedler girders without counter diagonals.
40	1880	Werder Bridge over the Nagold at Pforzheim.	Benkiser Brothers.	1	52,0	171	Trapezium-shaped girders with single diagonals and verticals.
41	1880	Roadbridge over the Saale at Calbe.	Gutehoffnungs Works.	1	106,6	350	Semiparabolic girders with verticals and double set of diagonals.

Between 1870 and 1880, during the great railway boom, an unusual amount of building went on all over Germany, railway bridges being specially favoured. Table III, therefore, contains only the more remarkable structures, of a span exceeding 50 metres (164 feet). Among these there are six railway bridges over the Danube, three over the Weser, four over the Rhine, seven over the Elbe and two over the Vistula. Among bridges of smaller spans, not included in the table, the following deserve to be mentioned: *Baumeister's* Werder Footbridge over the Murg at Gernsbach in the Baden part of the Black Forest, a semiparabolic girder with single diagonals and verticals and no counter diagonals, 36 metres (118 feet) wide, and the Schwedler girders of the Dreisam Bridge on the Freiburg and Breisach line, 34,2 metres (112 feet) wide, by the same designer, both bridges dating from 1871; further Schwedler's Oder Bridges at Dyhrenfurth, Steinau and Deutsch-Nettkow on the Breslau, Freiburg and Schweidnitz railway with 31 spans of 36,5 metres (120 feet) each, and Gerber's *trapezium*-shaped girders of the Roadbridge over the Lech at Füssen (see fig. 90), all built in 1874. While in Northern Germany the Schwedler and the semiparabolic girder types, with verticals, predominated, in the South of Germany parallel-girders with crossed diagonals and without verticals were as a rule preferred. The only exception is formed by the Main Bridge near Wörth on the Aschaffenburg and Miltenberg line of railway, with a span of 44 metres (144 feet), built by the Nuremberg Company, which has a *single* set of diagonals only. The longest railway viaduct in Germany is still represented by the Rhine Bridge near Wesel (see Nr 6, table III), which has a total length of 2000 metres (6562 feet).

Fig. 88. Danube Bridge at Gross-Prüfening. Gerber 1873.

When about 1880 the "boom" had passed away and the German main lines of railway had been practically all built, a pause naturally occurred in the construction of railway bridges, while at the same time there was a perceptible increase in the demand for roadbridges. Table III out of a total of 41 structures still contains 35 railway and only 6 roadbridges. At first the older types of girder-bridges used to serve as models for the latter, cantilevers predominating during a later stage of development; recently, however, following the example of the more important bridge companies, a decided preference has been shown in favour of archbridges.

Few large railway bridges were built early in the eighties. The *Elbe Bridge near Wittenberge* with two main spans of 55 metres (180 feet) each, constructed by the Harkort Company in 1882—83, has the last Schwedler girders of a larger size, belonging to this stage of development. For the rest the semiparabolic outline had nearly become typical for greater spans. Exceptions are only found in case of the large *Vistula Bridge at Dirschau* and the *Nogat Bridge at Marienburg,* built in 1888—93, which have become important chiefly by the trials preceding their construction (see page 7). As a result the 11 000 tons of iron contained in the superstructure of the Fordon Bridge were made entirely of *basic* metal, and the question regarding *the use of mild steel* in Germany took a decisive turn. Details of this and other more recent structures will be found in paragraph 22, where the constructive principles ruling at present are more fully explained and criticised.

Fig. 89. Vistula Bridge near Graudenz, Thorn and Marienburg line. 1879.

Table IV.

Remarkable German Girder Bridges of a span exceeding 60 metres (197 feet), built between 1880 and 1900*).

Number	Time of construction	Description of bridge	*Designer* and builders	Spans Number	Width in metres	Width in feet	Girder system
1	1883	Kinzig Bridge near Offenburg. Baden State Railways.	Gutehoffnungs Works.	1	64,5	212	Parabolic girders with verticals.
2	1885	Eider Bridge near Friedrichstadt, Holsteinische Marschbahn.	*Harkort Co.*	2 4	90,3 41,7	296 137	Parallel-girders with verticals and double set of diagonals. Small spans: Parabolic girders. Swingbridge of two spans of 27,0 metres (89 feet) each.
3	1885	Warnow Bridge near Rostock. Deutsch-Nordischer Lloyd, Waren and Warnemünde line.	*Harkort Co.*	1 2	67,5 19,3	221 64	Cantilever bridge without abutments. See fig. 40.
4	1886	Roadbridge over the Weser at Verden.	Beuchelt, Grünberg.	1 2	79,8 29,0	262 95	Semiparabolic girders. Double planking.
5	1889	Danube Bridge in the Eichhalde. Württemberg State Railways.	Gutehoffnungs Works.	1 1	63,0 31,0	207 102	Semiparabolic girders with verticals and two sets, parallel girders with one set of diagonals.
6	1889–91	1. New Vistula Bridge at Dirschau. 2. New Nogat Bridge at Marienburg, Dirschau and Marienburg railway.	*Schwedler. Mehrtens.* Harkort Co. See fig. 62, 67, 91, 92.	6 2	129,0 103,2	423 339	Girders of the truncated lens-type with intermediate flange and double set of diagonals, without verticals. Platform suspended below.
7	1890	Deime Bridge on the Labiau and Tilsit railway.	*Schnebel.* Beuchelt, Grünberg.	2	72,0	236	Semiparabolic girders with intermediate flange and double set of diagonals, without verticals. Swingbridge of 20 metres (66 feet) span.
8	1890—93	Road- and Railway Bridge over the Vistula at Fordon, Bromberg and Culmseen railway.	*Mehrtens.* Gutehoffnungs Works. Harkort Co.	5 13	100,0 62,0	328 203	Semiparabolic and parallel-girders with intermediate flange and double set of diagonals, without verticals. See fig. 32 and 68.
9	1891	Railway Bridge over the Liesenstrasse at Berlin.	Beuchelt, Grünberg.	3	82,1	270	Semiparabolic girders.
10	1892—93	Roadbridge over the Lesum at Burg (Bremen).	Union Works.	1	68,0	223	Semiparabolic girders with verticals and single set of diagonals. Ballast on buckled plates.
11	1893—94	Rhine Bridge near Roppenheim. Imperial Railways, Rastatt and Röschwoog line.	*von Bose.* Harkort Co. See fig. 93.	18 3	31,1 92,0	102 302	Semiparabolic girders with double set, parallel-girders with single set of diagonals, without verticals.
12	1894	Feuerbach Viaduct of the Württemberg State Railways.	Gutehoffnungs Works.	3	68,6	225	Parallel-girders with verticals and double set of diagonals.
13	1894—95	Roadbridge over the Weser at Bremen.	*Rehbock.* Harkort Co.	1 2	66,1 35,5	217 116	Cantilever bridge. See fig. 94.
14	1895—96	King William-Bridge over the Neckar Valley near Cannstatt.	Esslingen Works.	1 10	67,0 59,1	220 194	Parallel-girders with double set of diagonals, without verticals.
15	1896	Railway Bridges over the Zschopau (Saxony). 1. at Kriebethal. 2. at Waldheim.	Lauchhammer Works.	2 1	65,0 72,0	213 236	Parallel-girders with verticals and double set of diagonals. Parallel-girders with inclined end verticals.
16	1896	Railway Bridge over the Stecknitz Valley.	Gutehoffnungs Works.	1 3	70,0 53,0	230 174	Main span: Curved bottom flange. Small spans: Parallel-girders. Single set of diagonals with auxiliary verticals. Railway on top.
17	1897—98	Railway Bridge over the Saale at Grossheringen.	Union Works.	1 5	72,1 to 40,3	237 to 132	Semiparabolic girders like Nr. 10 with inclined end verticals.
18	1897—98	Cologne and Minden Railway Bridge for the Union Works at Dortmund.	Union Works.	2	77,7	255	Semiparabolic girders with double set of diagonals, no verticals.
19	1897—98	Roadbridge over the Rhine between Strassburg and Kehl.	*von Babo.* Harkort Co.	2 1	88,2 57,3	289 188	Parallel-girders with verticals and double sef of diagonals. See fig. 95.
20	1898—99	Railway Bridge over the Argen, Lake of Constance Circular Railway.	Esslingen Works.	1	74,0	243	Semiparabolic girders with double set of diagonals, no verticals. See fig. 96.
21	1899	Roadbridge over the Saale at Halle.	Lauchhammer Works.	2	70,0	230	Cantilevers, with verticals.

*) Tied arches are not included in this table. Comp. also Note on table I.

Fig. 90. Roadbridge over the Lech at Füssen. 1877.

Fig. 91. New Vistula Bridge at Dirschau. Perspective view of the interior. 1889—1891. With the old bridge in the background.

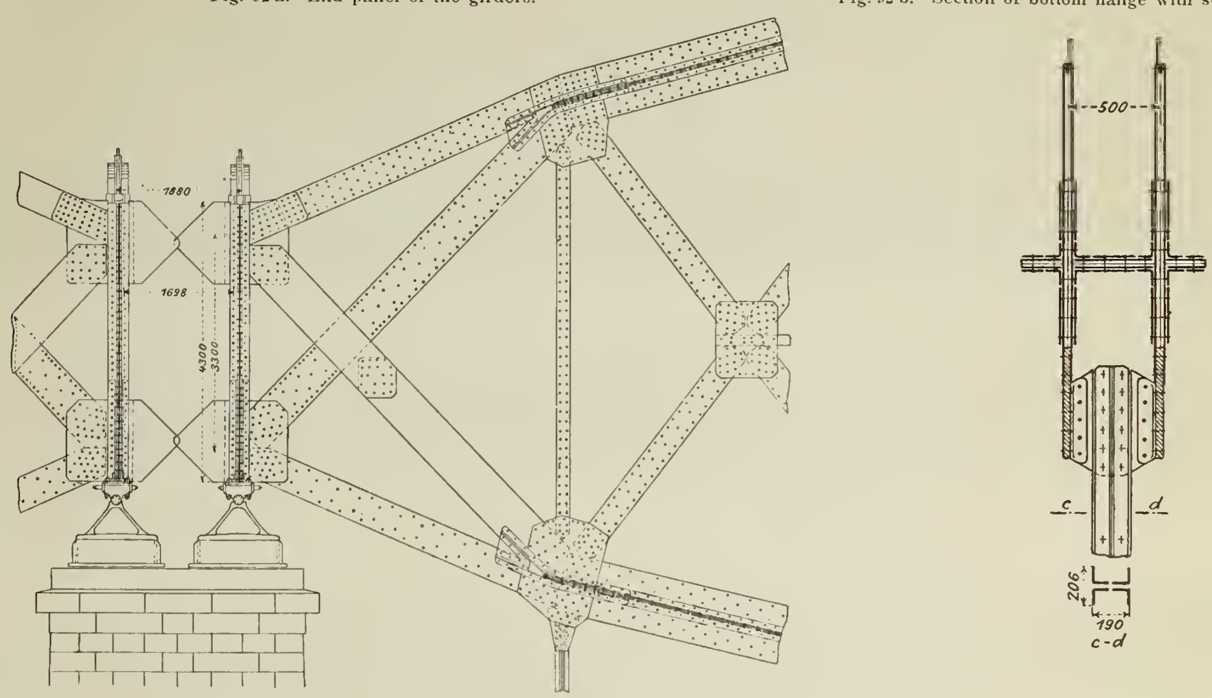
The chronological tables of remarkable German girder bridges contained in the present work are not to be considered as absolutely complete. Unfortunately is was not possible in every case to identify the designer; moreover, numerous smaller structures of excellent design could not be mentioned, as for instance such *viaducts* of recent construction, which are of short span only. It appears advisable to make a few remarks concerning the latter before proceeding further.

The building of iron viaducts[84]) has given occasion to the introduction of *iron piers,* by means of which the pressure on the soil can be reduced and consequently a saving be effected in the masonry blocks required for the foundation. At the Crumlin Viaduct, already mentioned on page 15, *Little* and *Gordon* in 1853 were the first to build iron piers, which like those of the suspension bridges of that period were made entirely of cast iron. The high piers of this kind were perfected by *Nördling* on the Orléans Railway, and the resulting French models were imitated in Spain, Italy and Austria at the end of the sixties and the beginning of the seventies. In the meantime the Americans, too, had commenced to build iron piers, applying to them their system of pin-connected nodes. While, however, high piers of European design were generally provided with *cast iron* columns of a tubular section, the Americans very soon tried to make them of malleable iron. For instance the piers of the Varrugas Viaduct, destroyed in 1872 and rebuilt in 1879, consisted entirely of wrought iron. In Europe wrought iron piers of great height were only built as late as the middle of the seventies. The bridge of the Palatinate Railways crossing the Zeller Valley near Marnheim (see Nr 14, table III) is still provided with cast iron pier columns. On the other hand the piers of the viaduct near Angelroda on the Arnstadt and Ilmenau line as well as the Nidda Valley Bridge near Assenheim*) on the Friedberg and Hanau line, built in 1880, are made entirely of wrought iron.

On *Köpcke's* initiative and following foreign (Norwegian and American) models, particular attention was paid to iron piers on the Saxon State Railways. The most important example of a bridge provided with *rocker piers* is represented by the *Oschützbachthal Bridge* on the Mehltheuer and Weida Railway (see fig. 97) with spans up to 36 metres (118 feet) and a height of 20 metres (66 feet). American *trestle bridges*, too, are strongly represented in Saxony, a prominent example being the bridge in the Mittweida Valley near Schwarzenberg (see fig. 98). The Müngsten Viaduct (see fig. 103) on each side of its big arch is also carried on trestles.

Fig. 92. New Vistula Bridge at Dirschau.
(Dimensions in millimetres.)

Fig. 92 a. End panel of the girders. Fig. 92 b. Section of bottom flange with suspended platform.



20. ARCH- AND SUSPENSION BRIDGES. After (in 1853) the Aare Bridge at Olten (see fig. 41) had opened the series of wrought iron arch bridges of the second half of the century, another ten years had to pass away, before this bridge system found imitation in Germany. The reason is partly to be found in the difficulties still attending the exact calculation of arches, partly in those attending their erection. The latter increase with the span and chiefly consist in the fact that it is possible only by taking extreme care, at the work as well as on site, to limit the action of the finished arch under its dead and live loads in a manner corresponding to that assumed in the design. For unless the dimensions of the arch at the moment of closing, when the loads have to be transmitted to the fixed points of support, exactly correspond to the actual temperature of the air at the time, as well as to the assumptions of the design, and consequently all initial strains are avoided, the erection of the bridge cannot he pronounced a success. It became necessary to gain experience in these difficult matters of routine, before designers as well as bridge works could think of approaching larger schemes of arched structures. Theory and practic had to go hand

*) Constructed by the Gutehoffnungs Works.

Fig. 93. Rhine Bridge near Roppenheim. Rastatt and Röschwoog line. 1893—94.

Fig. 94. Roadbridge over the Weser at Bremen. 1894—95.

in hand to an even greater extent, than at the erection of girder bridges. The difficulties referred to were not, indeed, always satisfactorily solved in case of the prominent arches, dating from 1860 to 1880, as enumerated in table V. When the arches of the St. Louis Bridge over the Mississippi, justly admired at their time of erection (1868 to 1874), were to be closed, many different ways of doing so (for instance by means of cooling the parts in question by ice, etc.) were tried without success, until finally a special piece had to be fitted in at the crown in order to make the structure act, at any rate as far as its own weight was concerned, as a compromise between a one-hinged arch and one without hinges[44]).

The construction of the large German archbridges, built between 1860 and 1880 (see table V) furnished some further practical methods of realising as far as possible the theoretical assumptions of the design. Table V already contains four bridges of a width approaching 100 metres (328 feet), which at that period was considered a very large span, viz. the well known railway bridges over the Rhine at Coblenz, at Rheinhausen and above Coblenz, and the old Elbe Bridge at Hamburg with its Lohse girders (see fig. 46). The latter system as well as that of the tied arch are here ranked with arches, because they have to be calculated in the same manner, though their abutment pressures, like those of girder bridges, have a vertical direction (see page 11).

Fig. 95. Roadbridge over the Rhine between Strassburg and Kehl. 1897—98.

Fig. 96. Railway Bridge over the Argen. Lake of Constance Circular Railway. 1899.

Fig. 97. Bridge with rocker piers over the Oschützbach Valley near Weida. 1884.

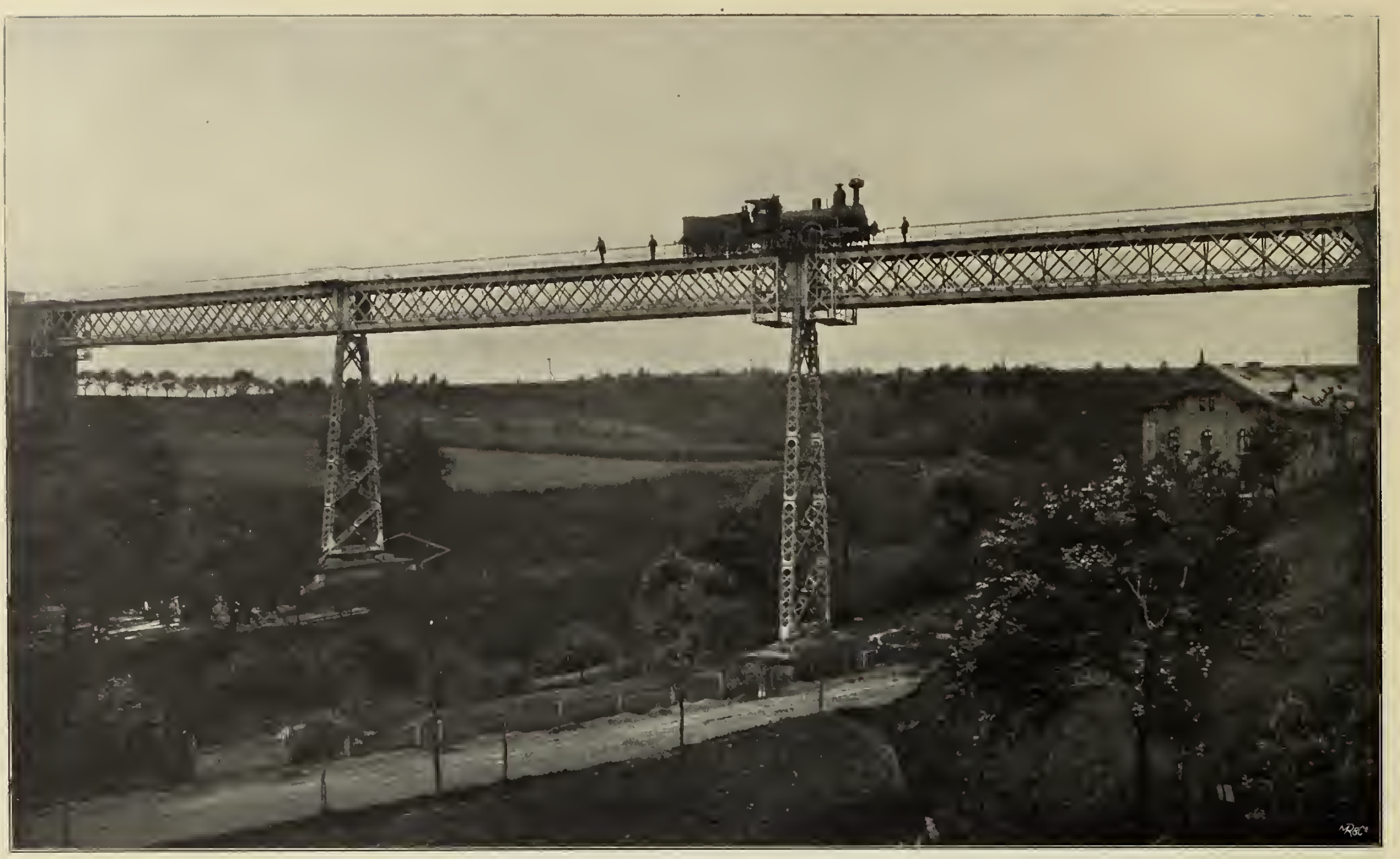


Fig. 98. Trestle Bridge in the Mittweida Valley near Schwarzenberg. 1889.

Table V.

Remarkable German Archbridges of a span exceeding 30 metres (98 feet), built between 1860 and 1880*).

Number	Time of construction	Description of bridge	Designer and builders	Spans Number	Width in metres	Width in feet	Girder system
1	1860—62	Road- and Railway Bridge over the Rhine at Constance. Baden State Railways.	*Gerwig.* Benkiser Brothers.	3	42,4	139	Continuous plate arch without hinges. Artificial adjustment of the action of temperature. Double line of railway.
2	1862—63	Old Rhine Bridge at Coblenz. Coblenz and Niederlahnstein railway.	*Hartwich.* Harkort Co., Cologne Engine Works.	3	96,7	317	Circular flanges with crossed diagonals. Hinges at the springing. Double line of railway. See fig. 42.
3	1865	Ruhr Bridge near Mühlheim on the Osterrath and Essen line.	*Hartwich.* Cologne Engine Works.	3	36,1	118	Braced parabolic arch. Double line of railway. In addition 7 arched tide spans.
4	1866	Footbridge over the Böllatfall at Hohenschwangau.	*Gerber.* Nuremberg Co.	1	35,0	115	Arch without hinges. See fig. 99.
5	1867	Neckar Bridge near Jaxtfeld. Baden State Railways.	*Becker.* Benkiser Brothers.	5	36,8	121	Arch with braced spandrel and hinges at the springing. Double line of railway.
6	1868—72	Elbe Bridge at Hamburg and Harburg. Venlo and Hamburg railway line.	*Lohse.* Harkort Co.	7	99,2	325	Lens-shaped girders with arched flanges, connected by verticals. Without horizontal thrust. See fig. 46.
7	1869	Tauber Bridge near Weikersheim. Württemberg State Railways.	*Morlock.* Esslingen Works.	3	30,5	100	Braced arch with hinges at the springing. Single line of railway.
8	1873	Rhine Bridge at Rheinhausen. M.-Gladbach and Duisburg line.	*Hartwich.* Gutehoffnungs Works.	4	97,0	318	Like Nr. 2 with tide spans and swing-bridge. See fig. 43.
9	1875—76	Roadbridge over the Neckar at Heidelberg-Neuenheim.	*Gerstner. Bär.* Esslingen Works.	5	35,0	115	Braced arch with hinges at the springing.
10	1876—77	Obermain Bridge at Frankfort-on-Main**).	*Schmick.* *Ph. Holzmann & Co.* Benkiser Brothers.	1 2 2	36,8 35,0 31,5	121 115 103	Arches with braced spandrels, without hinges. Platform on top.
11	1876—79	Rhine Bridge above Coblenz. Berlin and Metz railway.	*Hilf, Altenloh. Dörenberger.* Gutehoffnungs Works.	2	106,0	348	Like Nr. 2. See fig. 44. With two masonry arches.
12	1878	Moselle Bridge near Güls, Coblenz and Trier line.		3	65,6	215	Arch with crossed diagonals and hinges at the springing. Railway on top.

In Germany the building of archbridges has increased at a surprising rate during the last twenty years of the century (compare table VI). In number, quality and variety of arch structures Germany at present surpasses all other countries, America not excepted, though as far as the span is concerned, the latter country at this moment occupies the first place. For the rest the Americans undoubtedly have been following German practice to some extent, the great *Viaduct at Müngsten* in particular (the erection of which will be described in the Appendix) having served them as a model. This is proved by the erection of the new Roadbridge over the Niagara, with an arched span of about 256 metres (840 feet) and a height of 45,7 metres (150 feet), where, following the precedent of the Müngsten Bridge, the structure at first was made temporarily to act as a three-hinged arch, in order to be able, by the application of hydraulic pressure at the crown, to close it as a two-hinged arch in accordance with the assumptions made in the calculation. It is, moreover, gratifying to German engineers to note that this most admirable product of recent American bridge practice was originated by the scientifically trained intellect of German designers. The German-Americans *C. C. Schneider, P. L. Wölfel* and *F. C. Kunz*[44]) of the Pencoyd Ironworks, Philadelphia, together with the stubborn energy of their American cooperators, have brought this great work to a successful issue.

No better examples of the successful working together of theory and practice can be found than the Müngsten and Niagara Bridges just referred to. They decisively prove the possibility of building up even statically undetermined structures in perfect agreement with the assumptions of the design and with a sufficient degree of safety,

*) Among remarkable archbridges of smaller span the following may be mentioned here: The railway bridges over the Trankgasse and the Lupusplatz at Cologne, designed by *Hartwich* and constructed (in 1859) by *Harkort*, the roadbridges over the Kinzig near Gelnhausen and over the Lahn at Ems, built in 1862—63 by *Schmick*, further the two Rhine Bridges at Basle, built in 1877—82, and the Fulda Bridge near Hannoversch Münden, built in 1879—80[85]), all by *Lauter* (of the firm of Ph. Holzmann & Co. at Frankfort).

**) The Untermain Bridge, built by Schmick in 1871—74, is of similar design.

by making use of modern methods of calculation as well as suitable mechanical appliances at the erection. If a *temporary hinge* has to be inserted at the crown for that purpose, as was done first at the erection of the Müngsten Bridge, this expedient appears quite as efficient as that of the so-called *open joints*, often resorted to at the building of masonry arches of wide span.

Quite recently the *stiff tied arch*, lying above the platform, has come into great favour; on page 30 it has been already compared to the arch stiffened by a beam. A novel constructive arrangement, first introduced by the Harkort Company in case of tied arches, viz. the *freely suspended and freely moveable platform*, as described in detail in paragraph 22, deserves particular attention. Fig. 102 represents a tied arch of smaller span, viz. the footbridge over a branch of the Spree near the Mühlendamm, Berlin, which deserves to be mentioned on account of the tasteful design of its ornamental ironwork. Some further details of bridges enumerated in table VI will be found in the *Appendix*, which contains a description of the exhibition of German bridge works at Paris.

Fig. 99. Footbridge over the Böllatfalls at Hohenschwangau. Gerber 1866.

Fig. 100. Road- and Railway Bridge over the North Sea-Baltic Canal at Grünenthal. 1891–92.

Table VI.

Remarkable German Archbridges of a span exceeding 50 metres (164 feet), built between 1880 and 1900.

Number	Time of erection	Description of bridge	*Designer* and builders	Spans Number	Width in metres	Width in feet	System
13	1882—85	Roadbridge over the Rhine at Mayence-Castel.	*Lauter, Thiersch. Bilfinger.* Benkiser Brothers.	1 2 2	104,0 88,0 87,0	341 289 286	Circular flanges with bracing, and hinges at the springing. Comp. the remarks on page 41.
14	1884—87	Roadbridge over the Northern Elbe at Hamburg.	*A. Meyer, Engels. Gleim.* Harkort Co.	3	101,0	331	Lohse system like Nr. 6 and fig. 46.
15	1889—90	Roadbridge over the Main at Kostheim.	Nuremberg Co.	1	60,2	197	Like Nr. 13.
16	1890—93	Railway Bridge over the Northern Elbe at Hamburg. Hamburg and Hanover line.	Gutehoffnungs Works.	3	99,2	325	Lohse system like Nr. 6. Double line of railway.
17	1891—92	Road- and Railway Bridge over the North Sea-Baltic Canal near Grünenthal.	*Greve. Eggert.* Nuremberg Co.	1	156,5	513	Crescent-shaped arch with two hinges. See fig. 100.
18	1891—93	King Charles-Roadbridge over the Neckar at Cannstatt.	*Leibbrand.* Esslingen Works.	1 2 2	50,5 48,0 45,5	166 158 149	Plate arch with two hinges. Platform on top, supported by verticals.
19	1892—93	Road- and Railway Bridge over the North Sea-Baltic Canal at Levensau.	*Lauter. Matthesius.* Gutehoffnungs Works.	1	163,4	533	Circular flanges with bracing and two hinges. See fig. 101.
20	1892—95	Carola-Roadbridge over the Elbe at Dresden.	*Klette.* Königin Marien-Hütte.	1 2	52,9 50,0	174 164	Three-hinged plate arch with stiffened spandrels.
21	1893—97	Emperor William-Bridge over the Wupper-Valley at Müngsten. Remscheid and Solingen line of railway.	Royal Railway Board at Elberfeld. *Nuremberg Works.*	1	170,0	558	Braced parabolic arch without hinges. Adjoining parallel-girders on trestles. Double line of railway. See fig. 103.
22	1895—96	Roadbridge over the Danube at Straubing.	Royal Building Department at Deggendorf. Nuremberg Works.	1	91,0	299	Braced arch with two hinges. See fig. 104.
23	1895—98	Roadbridge over the Aare at Berne.	Gutehoffnungs Works. Bell. *von Bonstetten,* Simons, *von Fischer.*	1 5	114,9 34,4	377 113	Main span: Braced arch without hinges. Side spans: Plate arches. See fig. 179 (Appendix).
24	1897—99	Roadbridge over the Rhine at Bonn.	*Gutehoffnungs Works.* Schneider, *Möhring.*	1 2 1	187,2 93,6 32,5	614 307 107	Braced arch with two hinges. See fig. 105, 69 and fig. 173 to 178 (Appendix).
25	1897—99	Roadbridge over the Rhine at Düsseldorf.	*Gutehoffnungs Works.* Ph. Holzmann, *Schill.*	2 4	181,3 57,6 to 63,4	595 189 to 205	Like Nr. 24. See fig. 106.
26	1897—99	Roadbridge over the Southern Elbe at Harburg.	*Nuremberg Co. Gleim, Thielen.*	4 6	100,1 31,7	328 104	Braced tied arch. See fig. 47 and 48.
27	1897—99	Roadbridge over the Moselle at Trarbach.	*Harkort Co.*				Same system. See fig. 107, 108 and 71.
28	1898—1900	Roadbridge over the Rhine at Worms.	*Nuremberg Co.* Grün & Bilfinger, *Hofmann.*	1 2	105,6 94,4	347 310	Braced crescent-arch with two hinges. See fig. 109, 70, 184 and 185 (Appendix).
29	1898—1900	Railway Bridge over the Rhine at Worms. Worms and Rosengarten line.	*Harkort Co.* Schneider, *Frentzen.*	2 1 17	102,2 116,8 34,5	335 383 113	Still in course of construction. Braced tied arch. See fig. 110.
30	1900	Railway Bridge over the Elbe at Dresden, Dresden and Leipzig line.	*Köpcke. Krüger.* Klönne.	3 1 1	65,8 37,6 24,0	216 123 79	Continuous girder for four lines of railway. Crossed diagonals with intermediate flange. Platform on top. Horizontal thrust of about 1000 tons, produced by means of a three-hinged arch, artificially loaded.
31	1900	Roadbridge over the Elbe at Magdeburg. In course of construction.	*Union Works.* Ph. Holzmann.	1	135,0	443	Two-hinged arch with two masonry arches. See fig. 111 and 112, also 194 and 195 (Appendix).

Fig. 101. Road- and Railway Bridge over the North Sea-Baltic Canal near Levensau. 1892—93.

Fig. 102. Footbridge near the Mühlendamm, Berlin. 27,5 metres (90′ 3″) span. 1894.

Fig. 103. Emperor William-Bridge over the Wupper Valley near Müngsten. 1897.

In contrast to arches *suspension bridges* at no time have been regarded with much favour in Germany. The oldest German examples are represented by 1. the chainbridge over the Regnitz at Bamberg, erected in 1829, with a span of 64 metres (210 feet); 2. the two bridges built by *Wendelstadt* (see page 12) over the Weser at Hameln (in 1839) and over the Neckar at Mannheim (in 1845) respectively; 3. that built in 1850 by *Malberg* near Mülheim-on-the-Ruhr. Of these the three named first have had to be pulled down between 1880 and 1890 on account of excessive vibration. The Bamberg and Mannheim chainbridges in 1889—91 were replaced by statically determined cantilever bridges, constructed by the Nuremberg Company (see fig. 38 and 39). In place of the Weser Bridge a cantilever of an outline resembling that of a suspension bridge was built, the remains of Wendelstadt's old structure being finally made use of at the erection of another Weser Bridge near Hessisch Oldendorf (see fig. 113).

Schwedler's design, awarded first prize, of a chainbridge at Cologne (see fig. 14) and Lentze's design of a chainbridge of 5 equal spans over the Vistula at Dirschau have already been mentioned; the historical development of stiffened suspension bridges, too, has been shortly referred to (see page 32). As far as Germany is concerned, people only quite recently have begun to pay more attention to suspension bridges, undoubtedly in consequence of the high commendation gained by German designs of this class at the competions of Budapest, Bonn and Worms, which

Fig. 104. Roadbridge over the Danube at Straubing. 1896.

Fig. 105. Roadbridge over the Rhine between Bonn and Beuel. 1897—99.

have been repeatedly referred to. *Kübler's cable bridge over the Danube* (see fig. 55), with a main span of 300 metres (1017 feet), triumphed over all other designs emanating from many countries, also as regards cost, and the same designer's *cable bridge over the Rhine,* with a main span of 212 metres (696 feet) (see fig. 56), contained only chainbridge, with the chain made of *nickel-steel* (see fig. 114). For the *nickel-steel links* of this chain *Krupp* had guaranteed a tensional resistance of 70 to 85 kilos per square millimetre (44,5 to 54 tons per square inch) with a limit of proportionality of 48 kilos (30,5 tons) and a ductility of 15 per cent[86]. The total cost amounted to 3 800 000 Marks

Fig. 106. Roadbridge over the Rhine at Düsseldorf. 1897—99.

Fig. 107. Roadbridge over the Moselle at Trarbach. 1897—99.

3134 tons of iron, i. e. about 7,4 tons per metre run of bridge, while the weight of the competing chainbridge of the Nuremberg Company, the main span of which was slightly larger, viz. 225 metres (738 feet), amounted to 5322 tons or about 11,8 tons per metre. At the competition for a roadbridge at Worms the *Nuremberg Company,* together with *Grün & Bilfinger,* a firm of builders, and *Hofmann,* an architect, had handed in the design of a (£ 190 000), i. e. not much more than the actual cost of the archbridge since erected (see fig. 109).

According to this there can be no doubt that for spans varying from abaut 700 to a thousand feet suspension bridges have a good chance in competing with girders and arches, more particularly in cases like those at Bonn and Cologne, where a favourable aesthetic effect of the structure forms one of the principal conditions. For such spans

Fig. 108. Roadbridge over the Moselle at Trarbach. View of portal.

Fig. 109. Roadbridge over the Rhine at Worms. 1898—1900.

cable and chain would enter into sharp competition. The fact that the chain is a good deal heavier than the cable and consequently, other circumstances being equal, requires lighter stiffening girders, would speak in its favour.

Among more recent German suspension bridges the *Loschwitz Bridge* (see fig. 61), the remarkable design of which has already been described on page 36, has the largest

Fig. 110. Railway Bridge over the Rhine at Worms. Worms and Rosengarten line. 1898—1900.

span, its central opening being 150 metres (492 feet) wide. It appears questionable whether a heavy *rivetted* construction like that chosen in this instance is really suitable for long span suspension bridges; at any rate, a structure of this character as to its weight can scarcely compete with a cantilever bridge, the latter having the additional advantage of possessing only *vertical abutment pressures*. In case of small spans, a suspension bridge of any design under no circumstances can successfully compete with other systems, as far

Fig. 111. Roadbridge over the Elbe at Magdeburg. In course of construction. 1900.

as cost is concerned, because the necessity of providing anchorages and large masonry blocks, to which they are fixed, more than balances the advantage of a reduction in the bending moments resulting from the presence of the horizontal force. For this reason suspension bridges of smaller span are only chosen in cases, where particular stress is laid on a very light and pleasing appearance of the structure. If, on the other hand, *Leibbrand* and *Kübler* designed the *Langenargen Roadbridge* on the Lake of Constance as a cable bridge, both designers were no doubt actuated by the wish, certainly justified under the circumstance, not to let pass this favourable opportunity of actually erecting a cable bridge of modern construction, after so many designs had been made without any tangible result.

The Langenargen Bridge (see fig. 115 to 118) contains a number of remarkable details requiring some explanation. Each of its two cables has a diameter of 132 millimetres ($5^3/_{16}$ inches) and consists of six wire ropes of spiral twist, each formed of 37 wires, 6,1 millimetres ($^{15}/_{64}$ inch) thick, and a core of also 37 wires, 6,3 millimetres ($^1/_4$ inch) thick. The cable is made of galvanized cast steel wire of a tensional resistance of 130 kilos per square millimetre (82,6 tons per square inch) with a ductility of 4 per cent in case of the outer ropes, while the figures for the inner rope are 90 to 100 kilos (57 to 63 tons) and 4,5 per cent respectively. The ultimate tensile resistance of each of the two cables was calculated to amount to about 890 tons. No testing plant in existence being capable of exerting a force like this, the engineers had to be content to test single wires taken from the cable at the Stuttgart Testing Works.

The cables of the bridge are suspended with a pitch of 9 metres (29′ 6″) and inclined towards each other in a manner that their distance decreases from 10 metres (32′ 9″) at the piers to 6,82 metres (22′ 4″) at the centre (see fig. 116). On top of the piers they rest on cast iron bearings (see

fig. 117), which transmit the pressure to the lower bearing plate by means of six cast steel rollers of a diameter of 125 millimetres (about 5 inches) and a length of 0,5 metre (1′ $7^5/_8$″). Within the masonry the cable is bent over an intermediate bearing, supported by two I irons, and ends in a head piece forged of steel, bearing against the masonry by means of iron joists and plates (see fig. 118).

The Karl Works of the firm of Felten & Guilleaume at Mülheim-on-Rhine, which supplied these cables, in manufacturing its so-called *patent-locked cables* (see fig. 120) proceeds with the greatest possible care, scarcely surpassed in that respect by any other German or foreign establishment. More particularly the *connection of the cable head* (see fig. 119) has proved to be of such strength, that even when tested up to breaking point it remained perfectly sound, the cable giving way in the middle. No doubt results like these can only be obtained by taking the utmost care during the manufacture. After the ends of the wires have been spread out and coated with tin within the bore of the cable head, the cone of the latter, also tinned, is cast in with a very fusible kind of brass (shrinking little in cooling down), while all parts are being uniformly heated.

Fig. 112. Roadbridge over the Elbe at Magdeburg. Portal.

A striking proof of the excellent quality of the cables supplied by the Karl Works is furnished by the erection of the Müngsten Viaduct. The cables, 90 millimetres ($3^1/_2$ inches) thick, which on that occasion were used to tie back the great arch before it was closed, were, too, supplied by Felten and Guilleaume. When

Fig. 113. Chainbridge over the Weser at Hessisch Oldendorf. Built with the chains of the old Hameln Bridge. 1899.

a length of them, fixed to its head pieces, was tested at the Gustavsburg Bridge Works, the rupture took place in the middle between the cable heads, and the cable was found to possess a resistance exceeding the calculated one of 520 tons. It consisted of a core of 37 annealed steel wires, each 4,3 millimetres ($^{11}/_{64}$ inch) thick, of a tensional resistance of 100 kilos per square millimetre (63,5 tons per square inch), and six additional ropes, each containing 37 steel wires of a thickness of 4,2 millimetres ($^{5}/_{32}$ inch), the resistance in this case being 155 kilos (98,4 tons per square inch).

The limited competition, arranged in 1898 by the City of Cologne for the purpose of obtaining preliminary designs of a roadbridge crossing the Rhine, furnished additional evidence of the rapidly growing interest in suspension bridges. For no less than three very able designs of this class were handed in, viz. a cable- as well as a chainbridge by the *Harkort Company* and a cable bridge by the *Nuremberg Company*. A further sympton pointing in this direction may be found in the fact that the Nuremberg Company has recently patented a special arrangement of the cable, which not only admits of laying each rope in the easiest possible manner, but of *taking out and replacing each rope separately*. In case this novel system should stand the practical test, the chief objection still raised against the more general adoption of cable bridges, viz. that cables and cable anchorages cannot be replaced without great difficulty and expense, while the bridge is open, would fall to the ground.

The characteristic feature of the new arrangement (see fig. 122 to 125) above all consists in the perfect separation of each rope of the cable, when laid down, from the rest, their connection being effected later on. By this means the interstices between the different ropes are easier kept free from rust than in the case of a closer arrangement (see r, fig. 121). Moreover, in transmitting the forces P from the suspenders to the cable, is becomes possible to make use of as much area as appears desirable, while

Fig. 114. Design of a nickel-steel Chainbridge at Worms Nuremberg Company. (Dimensions in metres).

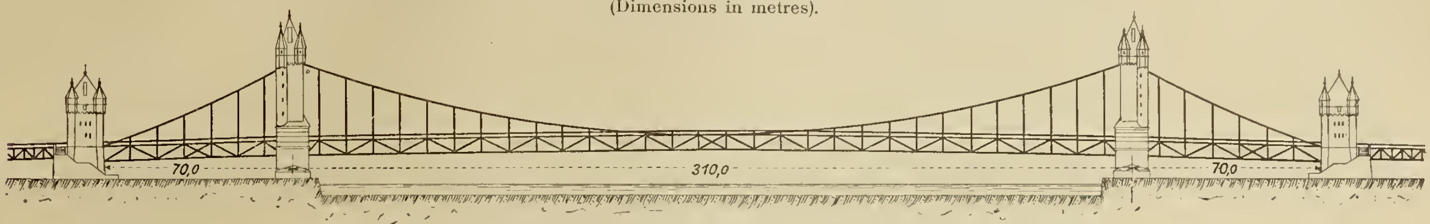
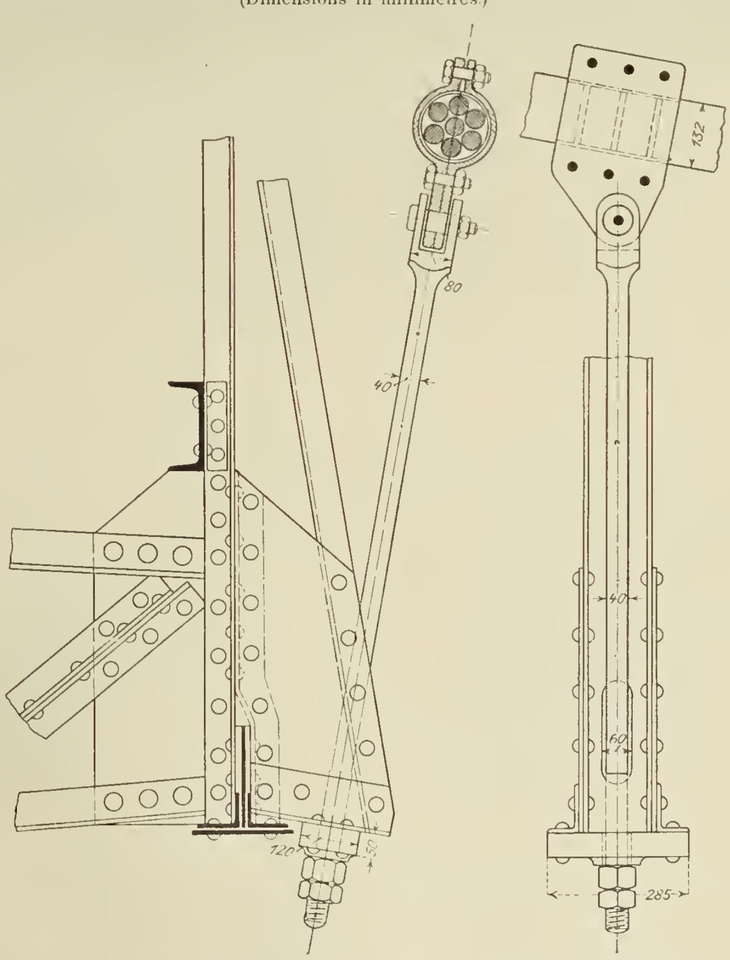


Fig. 115. Roadbridge over the Argen at Langenargen on the Lake of Constance. 1898.

Fig. 116. Detail showing connection of crossgirder to cable. Langenargen Bridge. (Dimensions in millimetres.)



in case of the older construction (see fig. 121) only the points marked p are in contact with the loop S. Finally the advantage is obtained, that each rope can be easily examined as well as replaced at every moment, provided the connections of the suspenders, the bearings on the piers and the anchorages are designed to suit this purpose.

The patents have already been taken out in France, England and America, while in Germany and Russia the preliminary application has been published. Protection is claimed for the *connection between suspender and cable* (see fig. 122 to 124) and for the *bearing of the cable on the piers* (see fig. 125). At the bearing on top of the piers the bottom row of wire ropes is supported by a steel casting of suitable shape, which transmits the entire pressure to the rollers or rockers. The remaining ropes are secured in their proper position by the grooved steel castings shown in the drawing.

In order to transmit the tensile strain of the suspenders uniformly to the wire cords of the cable, the latter have been grouped in vertical rows, their distance apart being secured by steel castings of a suitable form. The whole is enclosed in a flat bar loop, between the lower ends of which and the bottom wire rope a plug of special shape is inserted, which is being pressed against the top bent of the loop. This artificial pressure has to be of sufficient

Fig. 117. Langenargen Bridge. Cable Bearing on top of pier. (Dimensions in millimetres.)

Longitudinal section. Cross section a—b. Cross section c—d.

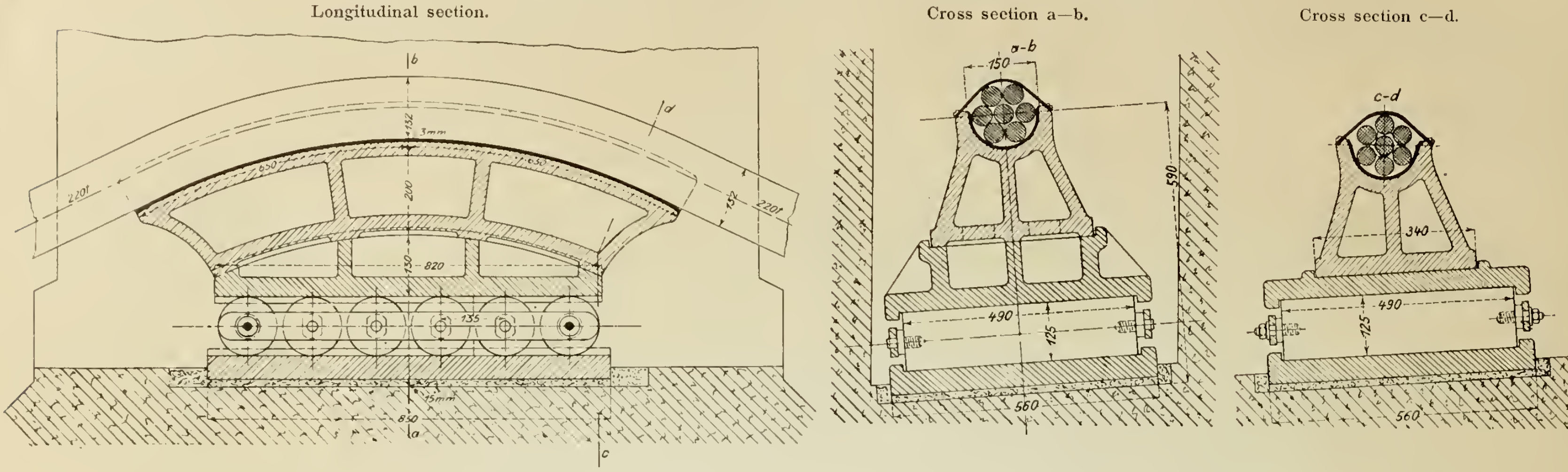
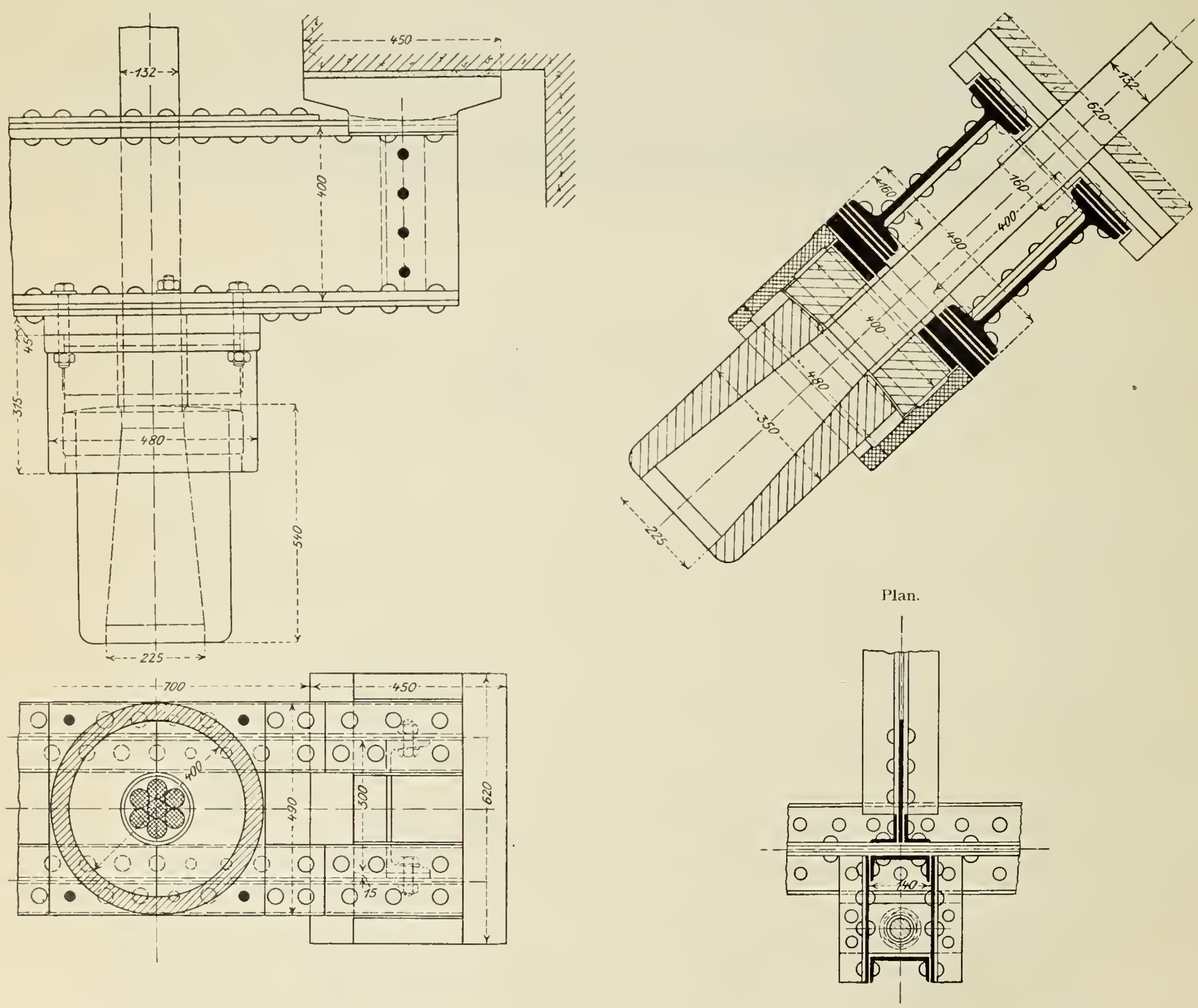


Fig. 118. Langenargen Bridge. Anchorage of cable. (Dimensions in millimetres.)

View and plan. Section.



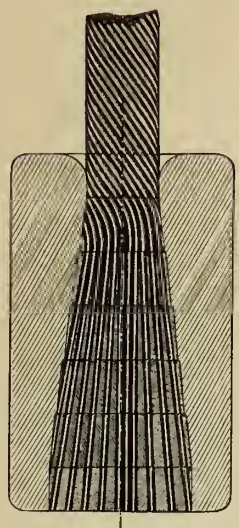


Fig. 119. Detail of cable head.


Fig. 120. Patent-locked cables by Felten & Guilleaume at Mülheim-on-Rhine.

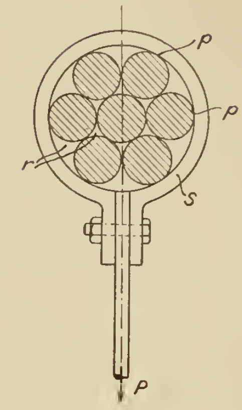


Fig. 121. Old way of connecting suspender.

Figures 122 to 125. Details of cables for suspension bridges by the Nuremberg Company.

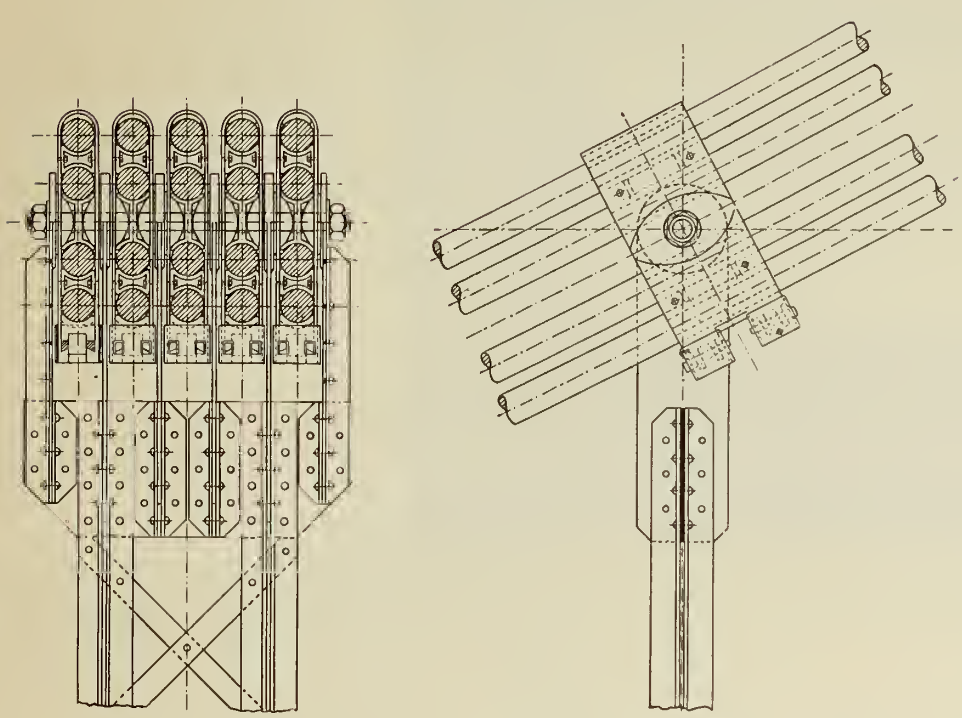


Fig. 122. Connection of suspender to cable.

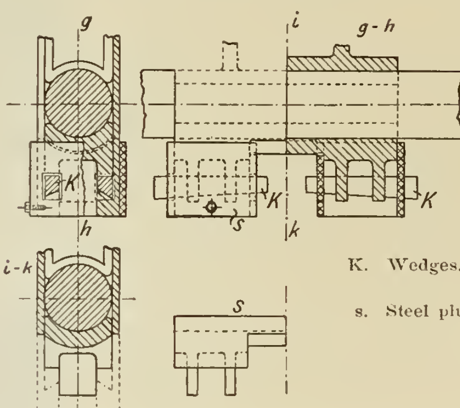


Fig. 123. Detail showing manner of closing the connection by wedges.

K. Wedges.

s. Steel plug.

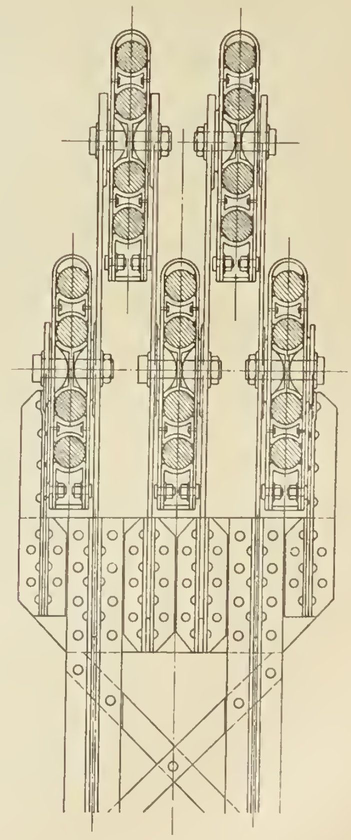


Fig. 124. Connection of suspender to wire ropes of cable, the latter being at different levels.

Fig. 125. Details of bearing on top of pier (Dimensions in millimetres).

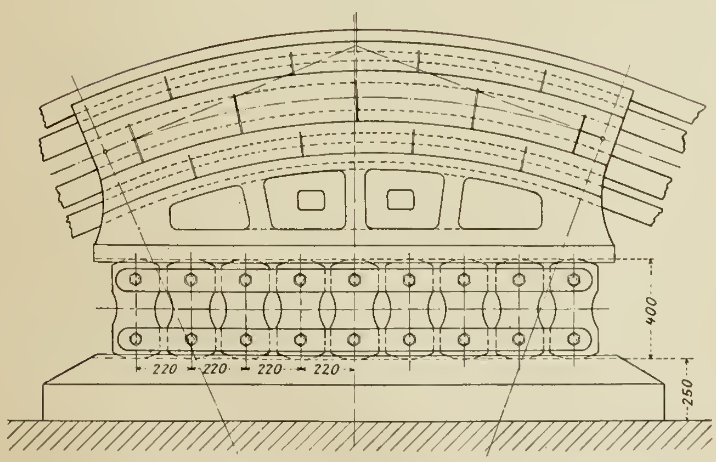


Fig. 125a. View.

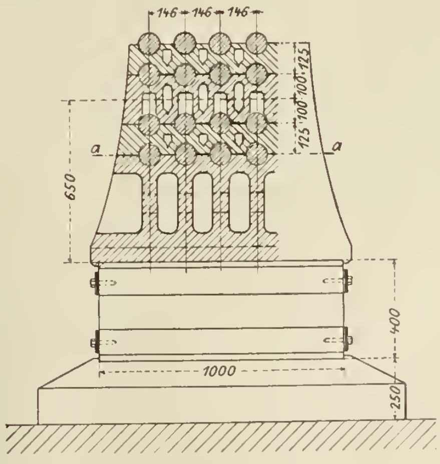


Fig. 125b. Section.

intensity to prevent the loop or the intermediate steel pieces from slipping on the ropes. The connection is closed either by bolting the ends of the loop to the plug or by means of wedges (see fig. 123). After the wire ropes of each vertical set have thus been joined together, the pin is inserted and the suspender fixed to it by means of the linkheads shown in the drawing.

A different arrangement of the wire ropes is represented in fig. 124. The vertical sets in this case are placed at different levels, each group having its own short pin and the connecting linkheads of the suspenders being of different length.

In *replacing* a single rope it is sufficient to relieve from strain the vertical set, of which the damaged rope forms part, by simply taking out the plug, during which operation the load of the bridge is to be reduced in proportion. There will then be no difficulty in inserting the new rope, the loop at the suspenders being easily bent open and the grooves at the bearing leaving a little play above the ropes. At the anchorage, of course, sufficient room is provided for putting in new ropes and fixing new cableheads.

The Harkort Company, too, has recently taken out patents of a *special node connection for stiffened cable bridges*, making use of collars, formed of two pieces and pressed against the cable by means of rings shrunk on warm, in order to obtain the amount of friction required*). The interstices are filled up with some fusible material.

Fig. 126. Railway Bridge over the Ellhofertobel near Röthenbach. Pin-connected nodes. 40 metres (131 feet) span.

21. GERMAN PIN BRIDGES. When the great influence was recognized, which secondary strains have on the degree of safety of a bridge, it was believed at first, that pin-connected structures were less liable to being affected by them than rivetted ones. *Gerber* consequently introduced his characteristic pin bridge type (see page 45), an example of which is shown in fig. 126. The opinion referred to, however, was a mistaken one. Already Manderla[81]) had pointed out that according to his observations a rotatory movement of the pin really takes place only in the rare cases, when its friction is overcome by very violent concussions. This was confirmed by American experience, more fully discussed on page 16, 17 and 24. It is only in case of smaller spans that the impact of rolling loads ever produces a turning movement round the pins, as American experience conclusively shows. In these instances, however, the too great mobility of the construction invariably proved troublesome, and the majority of American bridge works consequently was induced to provide all bridges of shorter span (say up to 55 metres or 180 feet) with connections rivetted up in the European manner[37]). In case of large spans the heavy pins, fitted in tightly, form a connection as rigid as a rivetted one and by that means provide the structure with the required amount of stiffness. There still remains, however, a great advantage of pin bridges over those with the nodes rivetted up, viz. the possibility of their rapid and easy erection, even in cases where no skilled workmen are to be had. Pin bridges for this reason have also gained some importance for those among German bridge works, which gradually are perfecting their arrangements for supplying foreign markets, notably the colonies beyond the sea. For a number of years already each of them has had its own special system of pin bridges, some of which have been perfected to a degree, that no longer any smith's work is required and not a single rivet need be inserted at their erection. The following is a short description of pin bridges, as they have been exported abroad in large numbers by the *Harkort Company*. In a few cases their pin system has also been selected for German bridges, as for instance the road-bridge over the Ems at Münster, built in 1881, and over the Lenne at Altena, built in 1882.

The majority of bridges to be sent out and erected abroad is of shorter span only, up to about 80 metres (270 feet). The following description refers to an average span of 61,5 metres (202 feet), as supplied by the Harkort Company to the Deli—Spoorweg—Maatschappy in Sumatra. Simple triangular systems are preferably chosen for the maingirders, because they exactly realize theoretical demands, even in case of slight inaccuracies in the length of any of the bars. The Harkort Company in most cases make use of parabolic girders with a bracing of single division, as shown in fig. 130. Type 1, being provided with pin connections in alternate panels, is used for girders with short bays, where the lengths of the flanges, extending over two of them, as well as the eyebars, are not too unwieldy to be conveniently shipped in one piece (up to about 8 metres, 26 feet). Type 2, showing pins at every node, is suitable for a greater length of panel, ranging from a minimum of 4 to about 8 metres (13 to 26 feet).

Parallel-girder systems, of course, can also be applied. Types 3 to 5, being "through-bridges" with high maingirders and an upper windbracing extending over their entire length, are particularly suited for bridges of larger span. Parabolic girders have the advantage of nearly uniform strain limits for all parts of the flanges; moreover, their bracing bars, being much weaker than those of

*) Impl. German Patent Nr. 108 936, dated Nov. 15, 1898.

Fig. 127. Node of top flange.

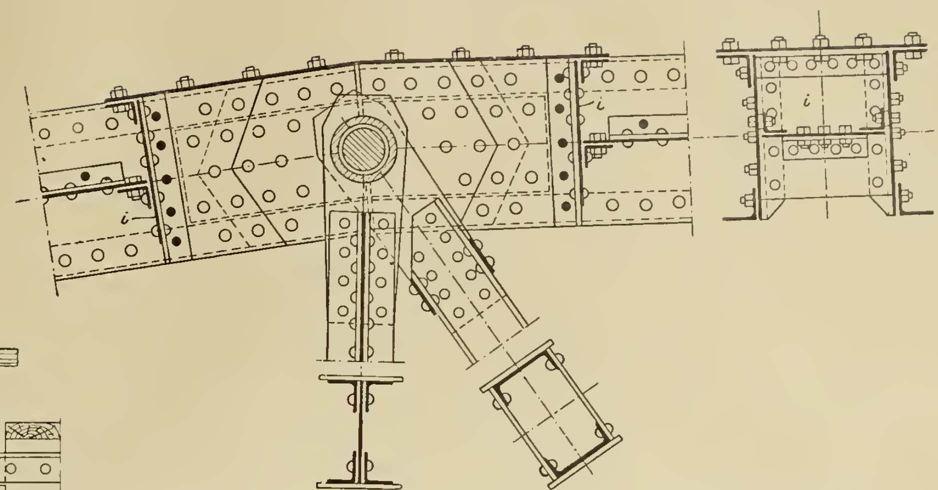


Fig. 128. Connection between vertical and crossgirder.

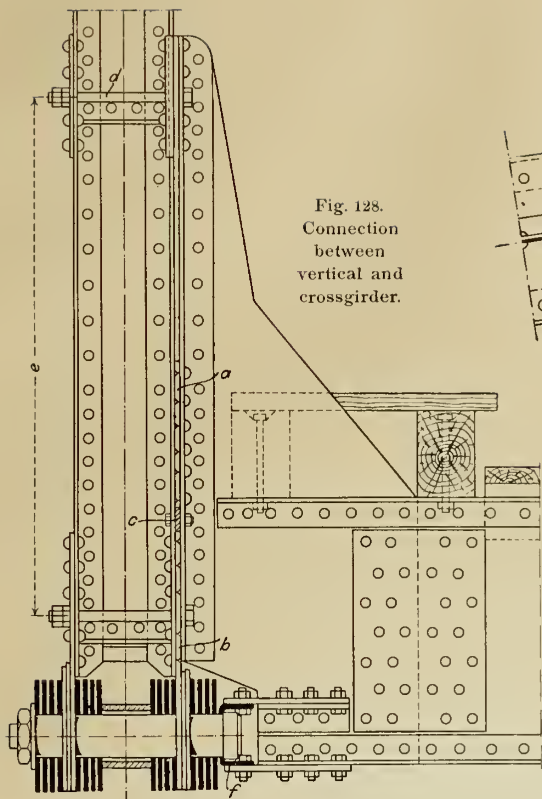


Fig. 130. Girder types.

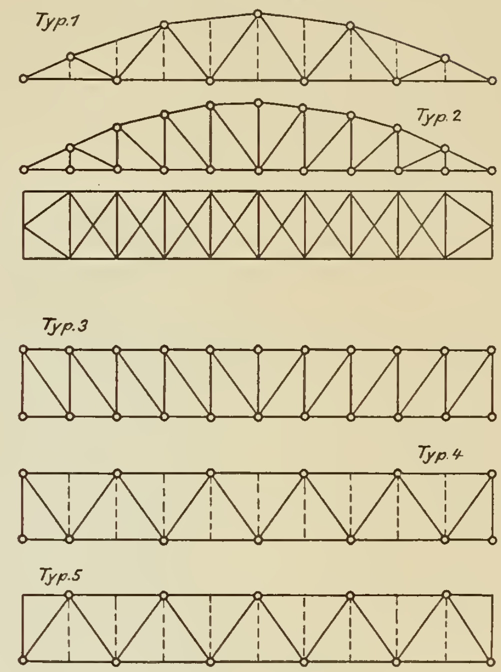


Fig. 129. Wind bracing.

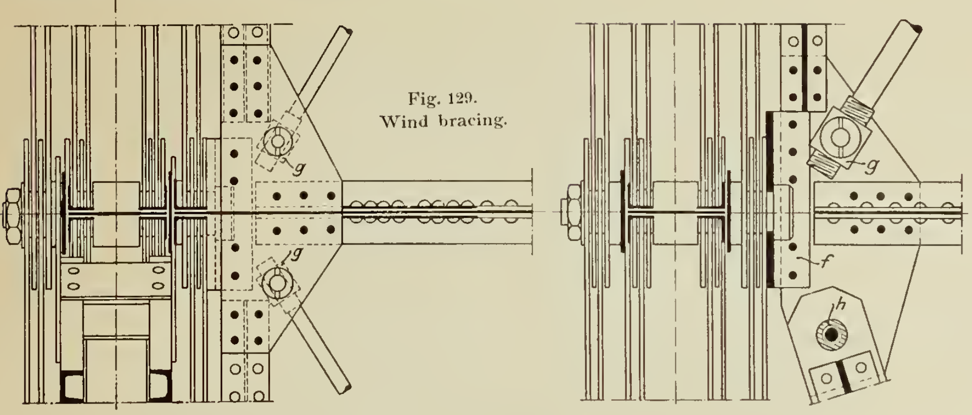


Fig. 131. End crossgirder.

Fig. 131 a. Section.

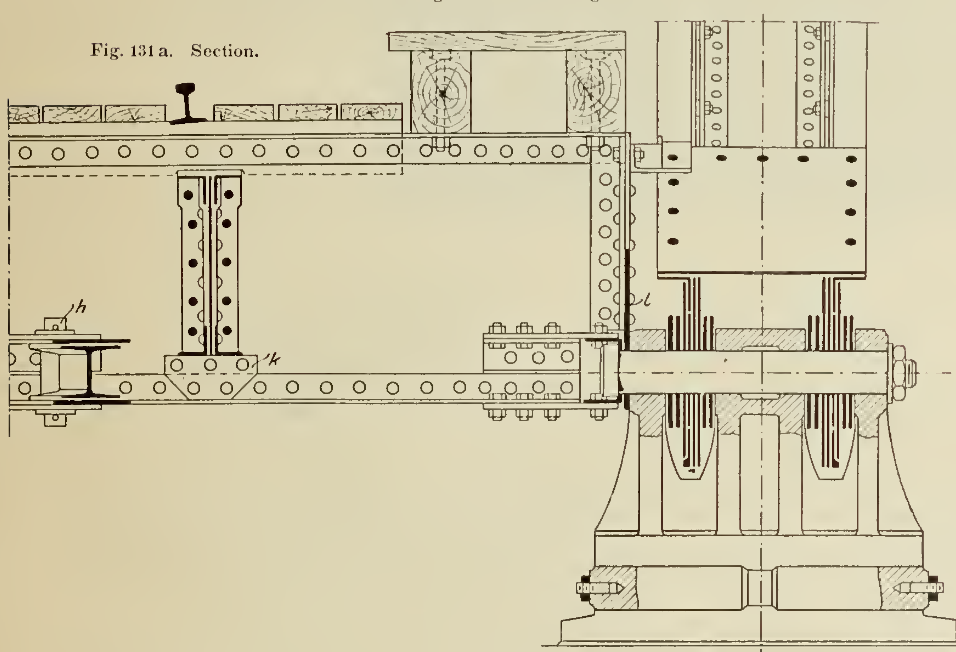


Fig. 132. Moveable bearing.

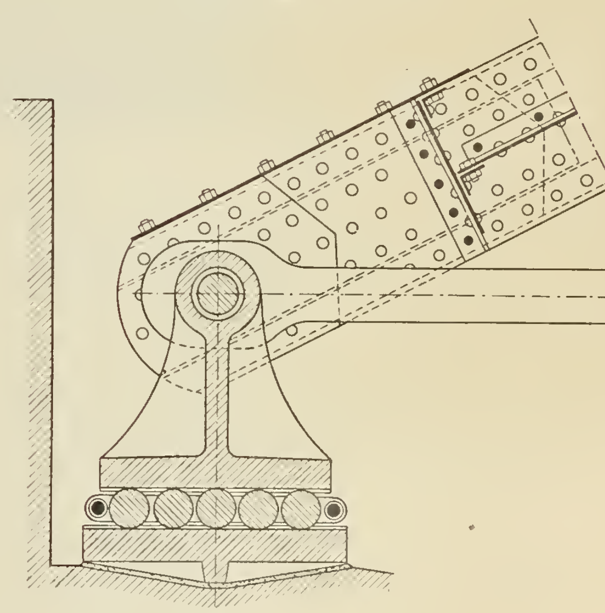
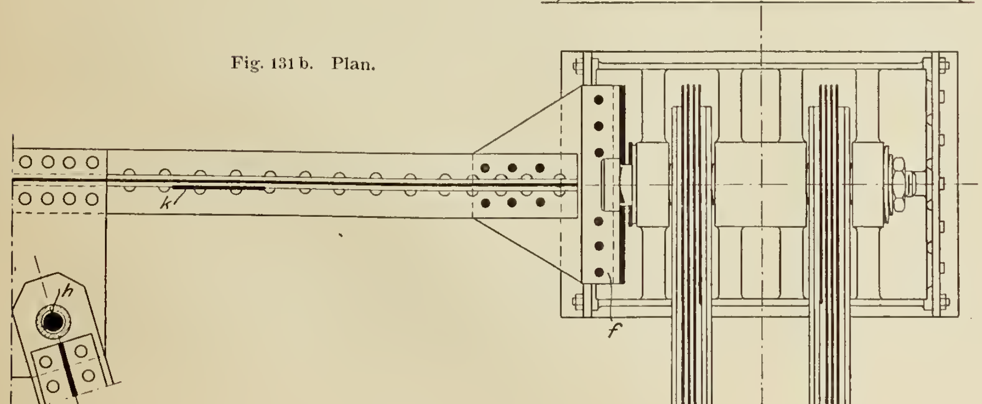


Fig. 131 b. Plan.



Figures 127 to 132. Details of pin bridges of the Harkort Company.

parallel-girders, play a more subordinate part, also with regard to their action on the mobility of the pins.

Of the details, shown in figures 127 to 132, the *eyebars of the bottom flange, the bracing bars, the top flange, the crossgirders and railbearers,* finally the *windbracing* and the *bearings* deserve particular attention.

The eyebars of the bottom flange as a rule are forged in one piece from the ingot, the pinholes being cut out afterwards; by exception they are made of flat bars with the linkheads rivetted on. The most suitable dimensions have been determined by experiments based on the demand of a tensile resistance of the eye at least equal to that of the body of the bar. The diagonals and verticals, to which their linkheads are connected by rivetting, are shown in section in figures 127 to 129.

flange during erection, on the other protecting all parts round the pin of the finished bridge against rain and wet.

The connection of the crossgirders to the vertical is formed by means of four bolts d, two plates a and b and a wedge c (see fig. 128). The plate a is fixed to the end of the crossgirder, the plate b, being at the same time the linkhead of the vertical, to the latter. Between the planed lower edge of a and the upper edge of b, also planed, a space of 60 to 80 millimetres ($2^3/_8$ to 3 inches), being equal to the pitch of the rivets, is kept open, which after the erection and adjustment of the crossgirders is closed by inserting the wedge c. The vertical pressure of the crossgirder is, therefore, taken by this wedge together with the plates a and b, while the bending moments between crossgirder and vertical, caused by wind pressure or by the

Figures 133 to 135. Erection of the pin bridges.

Fig. 133. First stage of erection.

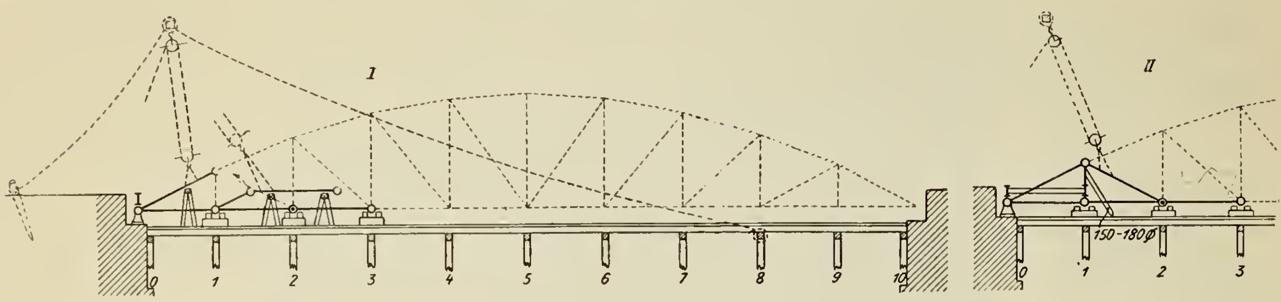


Fig. 134. Intermediate stages.

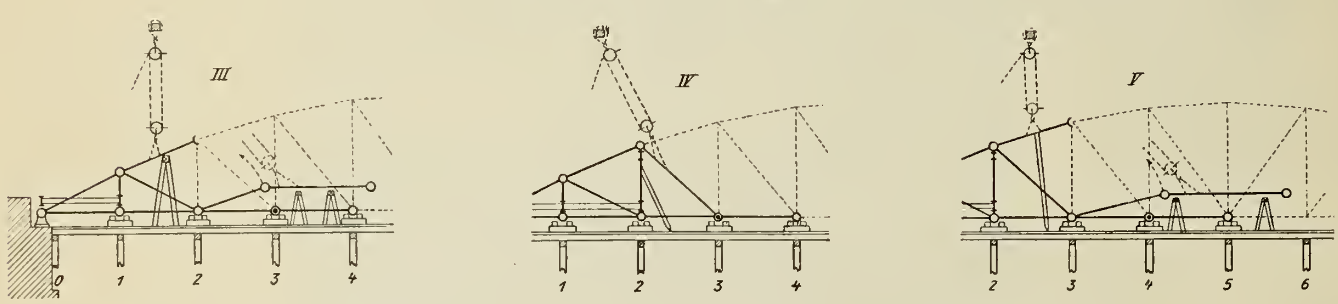
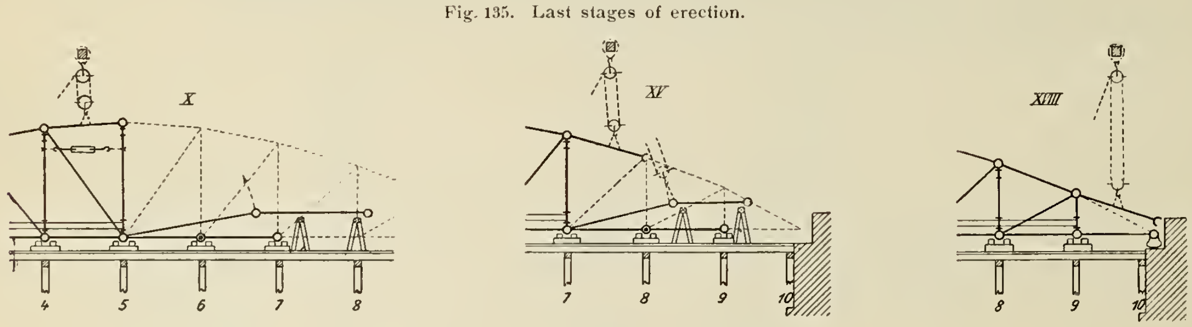


Fig. 135. Last stages of erection.



The links of the top flange are box-shaped (see fig. 127), strengthened at the nodes by rivetting on additional plates, corresponding to the actual pressure, and provided with a semicircular boring, which bears against *half* the circumference of the pin. *Open* joints are consequently formed at these points, facilitating the erection to a considerable extent. On each side of the pin full-webbed cross frames i (see fig. 127) are inserted, forming the termination of the secondary bracing, by which the flange is stiffened. In this manner a box-shaped space, open at the bottom, is provided round the pin and closed by a plate covering the joint of the flange. This plate is only fixed by means of bolts, allowing it to yield freely to any deformations of the structure. Thus it serves a double purpose: on the one hand temporarily connecting two adjoining lengths of the

deflection of the crossgirder, are transmitted by the bolts d, the diameter and distance e of which is to be determined accordingly. The *railbearers* are supported by special plates k; besides they are fixed to the crossgirders by means of angle irons and bolts (see fig. 131).

The details of the windbracing are shown in fig. 128 to 129. The inner ends of the pins, connecting the eyebars of the bottom flange, pass through ⊏ shaped pieces f, to which the upper and lower cornerplates are bolted, holding between them the tie rods of the windbracing. The cornerplates by means of pieces of angle iron are also bolted to the crossgirders, the latter consequently acting as posts to the windgirder. At the end panels the windbracing, being fixed to the middle of the end crossgirders, terminates in a *point* (see fig. 130, type 2). By this means

the complicated connections at the bearings are avoided. The end diagonals of the windbracing are fixed by means of vertical pins h, while the end crossgirder is supported on the bearing pin by the vertical plate l (see fig. 131). As the connection between the windbracing and the ordinary crossgirders may give rise to the erroneous impression that the latter too are resting on the pins of the bottom flange, it may be repeated here that this is not the case, the wedge c, which supports the crossgirder, being driven in only after the erection and adjustment of the bridge has been finished, the crossgirders being therefore lifted off the pin.

The manner of erecting a pin bridge of the Harkort Company has been represented in its different stages in figures 133 to 135. The scaffolding has to be arranged in a manner to support each node on piles as rigidly as possible, and to have at the floor level of the stage, which is about 60 to 80 centimetres (24 to 32 inches) below the bottom line of the structure, a clear working space of at least 1,5 metre (about 5 feet) on each side of the bridge. For the temporary support of the nodes blocks of wood or wedges are employed, each second or third node being, if possible, provided with jack-screws instead. The raising and fixing of the different parts of the structure is done in case of larger and longer bridges (in addition to the plant and appliances generally used) by means of a timber *travelling crane*, moving outside the maingirders and commanding the entire width of the bridge. For smaller and shorter spans an ordinary *gin* will be sufficient, kept in its vertical position by means of ropes. There being no space to enter more fully into the interesting details of the erection, the general mode of proceeding will be sufficiently clear from the sketches, figures 133 to 135. Fig. 136 illustrates the preliminary erection of pin bridges within the yards of the Harkort Company at Duisburg. Some further details of pin-connected bridges will be found in the Appendix.

Fig. 136. Bridge for Japan, 47,25 metres (155 feet) wide, as erected in the yards of the Harkort Company at Duisburg. 1890.

22. NEW DETAILS OF CONSTRUCTION. As it cannot be the writer's intention to minutely discuss all constructive features of a bridge, he confines himself to explaining the general principles underlying modern bridge design, demonstrating them by means of good recent examples. Other cases will be found in the Appendix, where the exhibition of German bridge works at Paris is briefly described. With regard to the constructive principles referred to, as applied to the so-called *through-bridges,* two parts of a bridge, each of them being self-contained, are to be distinguished: 1. the *main structure,* comprising the maingirders, the cross- and windbracings and the bearings; 2. the *platform,* including the platform girders and the bridge floor.

In contemplating the development of the maingirder *bearings,* it will be observed, how the tendency of accurately marking and fixing the theoretical point of support — at the same time allowing the girders to deflect freely under the load, as well as to extend longitudinally and laterally under the influence of temperature — has resulted in gradually giving up *surface* or *sliding bearings* in favour of *roller bearings,* and at a later stage of modern *hinged, pin-* or *rocker bearings.* At the same time it can be shown that designers tried to attain the same result by means of reducing the bearing area as well as by providing the bearing with a sectional form capable of uniformly distributing the pressure from the upper surface over the entire area. While, however, during the fifties sliding bearings were applied in somes instance to spans as large as 90 metres (295 feet), on the other hand even at that period hinged tangential bearings have been tried, differing not materially from those in general use to-day. This, as far as known, was first done by Werder, when building the Grosshesselohe Bridge, referred to on page 56. *Gerber,* too, on many occasions has made use of these bearings, and the Nuremberg Bridge Company still employs them whenever it is allowed to do so[86]). They have for instance been used

quite recently for the parallel-girders over the tide spans of the bridge crossing the Southern Elbe at Harburg, constructed by the Nuremberg Company. In this case they each carry two girders contiguous over the pier, the latter, therefore, being always centrally loaded. Though the two girders outwardly appear to be continuous, they are in reality only connected by a springy joint, allowing each girder to carry its own load without being interfered with by the other.

Figures 137 to 142. Details of recent bearings.

Fig. 137. Fixed bearing. Fig. 138. Bearing moveable in a longitudinal direction.

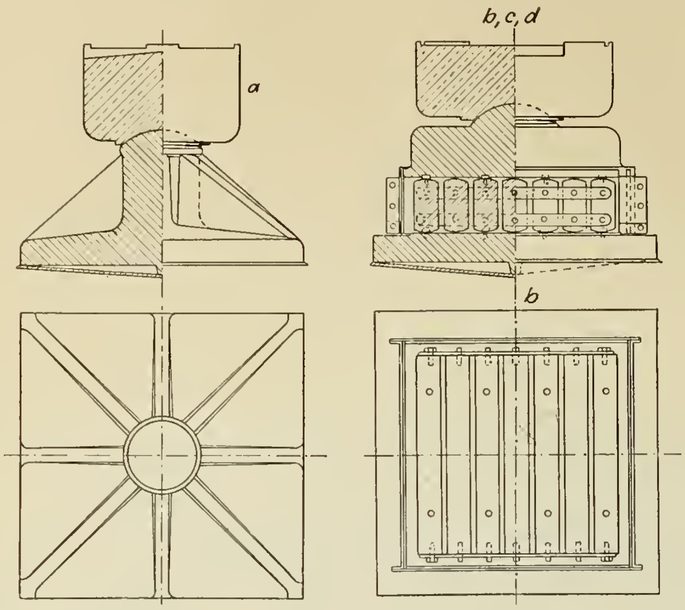
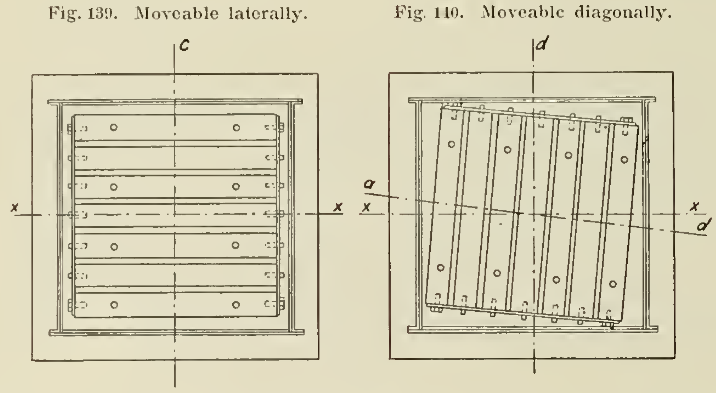


Fig. 139. Moveable laterally. Fig. 140. Moveable diagonally.

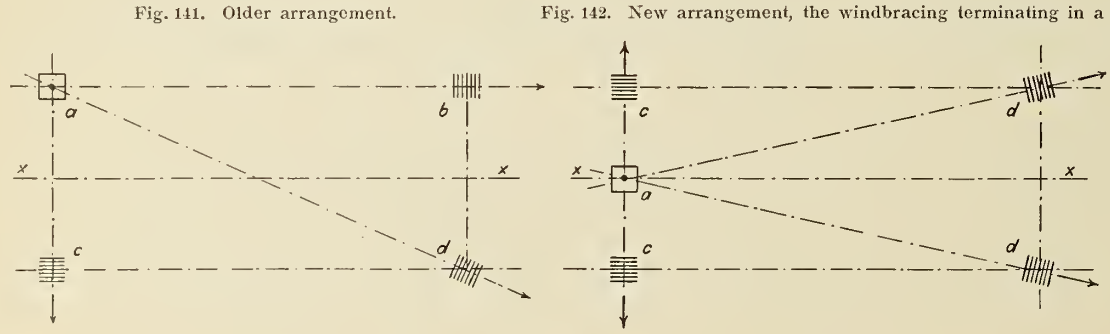


Schwedler gave preference to pin-bearings, though the latter do not fix the point of support as exactly as tangential bearings, the pin friction under varying bridge loads causing a small variation in the position of the resultant abutment pressure. At the bearings of the new Dirschau Bridge Schwedler in 1889 introduced rockers moving in a *transverse* as well as longitudinal direction, in order to provide for a lateral extension of the bridge. For the purpose of facilitating the return of the inclined rockers to their vertical position, he enlarged their section at the bottom, the centre of gravity being consequently very low down. There being two separate sets of them, *one above the other,* the upper set providing for the lateral, the lower for the longitudinal extension of the bridge, the total height of the bearing becomes comparatively great, a disadvantage particularly noticeable in the transmission of the wind force to the piers. For this reason *Köpcke* at the Loschwitz suspension bridge has placed his single set of rockers *diagonally* to the two directions of the movement.

Simplified bearings of this kind, moveable both longitudinally and laterally, have been recently perfected by the *Harkort Company,* as shown in figures 137 to 142, representing the bearings of the Moselle Bridge at Trarbach and those forming part of the design of a new Elbe Bridge at Magdeburg. Their arrangement is based on the assumption that the maingirders and the crossgirders of a bridge are being uniformly extended by the action of temperature, an assumption realised for instance in the case of both bottom flange and platform girders being placed entirely in the shadow of the bridge floor. The construction of these hinged bearings is considerably simplified by their upper and lower casting being both provided with *spherical surfaces,* fitting into each other. In that case two different models only are required for each span, viz. a fixed bearing a (see fig. 137) and three moveable bearings b, c and d (see figures 138 to 140). The three latter consist of identical parts, but the bearings b and c are placed at an angle of 90 degrees to each other, while at d the set of rockers is put diagonally. The bearing c, being moveable laterally, can be regarded as fixed in the direction of the girder, because its rollers or rockers are provided with a projection for the purpose.

The bearings shown in figures 137 to 141 in case of very large spans do not allow the main girders to extend under the action of vertical loads without some little resistance, though the latter may be insignificant compared to that of bridges without any bearings moveable in a transverse direction. This resistance, however, can still be considerably reduced by placing the bearings in the manner shown in fig. 142, as proposed by the Harkort Company for a bridge over the Elbe at Magdeburg. In this case the only fixed point of the structure is at a, which, being on the centre line of the bridge, at the same time forms the termination of the windbracing at the centre of its end post; c, c are bearings moveable transversely, d, d diagonally. It will be noticed that the angle, at which the bearings d are placed, is only half that shown in fig. 141, and that the resistance referred to above is proportionately smaller.

Fig. 141. Older arrangement. Fig. 142. New arrangement, the windbracing terminating in a point.



The constructive principle universally acknowledged to-day, that the *main structure* of a through-bridge should form a rigid system in space, has not been always recognized or acted upon during the early times of iron construction. The main carrying structure at that period was not as a rule regarded as an integral and self-contained system, but for the purposes of design it was divided into the maingirders, taking the vertical loads, and the cross- and windbracings, providing for the lateral forces. In too many cases attention was only paid to the calculation and design of the maingirders, whilst that of the transverse bracings was neglected, the latter being arranged by the designer at his own discretion, either too little or too much being done to it. This state of things came to a sudden end, when in 1892 the terrible accident took place at the Mönchenstein Bridge in Switzerland, which broke down under a passing train, causing a great loss of life. A general and deepgoing distrust of the soundness and durability of existing iron bridges at once became apparent among the public and found its immediate expression in newspaper articles of every degree of

strong horizontal posts, or even adding inclined stays in order to stiffen the corners formed by them with the verticals of the maingirders. If these posts and frames have nevertheless been added in case of the Vistula Bridge at Fordon (see fig. 32 and 68), this has been done against the intention of the designer. Stiff end portals and a windbracing consisting of crossed diagonals of a section capable of resisting compression are perfectly sufficient to ensure the required transverse stability of through-bridges. Moreover, the latter will not be unfavourably affected by providing *moveable bearings for the crossgirders* on the bottom flange of the maingirders. Moveable bearings of this kind were, as far as known, first applied in 1882 to 1883 at the Rhine Bridge near Reenen*) on the Amersfoort and Nymwegen line of the Dutch State Railways. Later on they have been extensively adopted for Russian railway bridges[57]). At the Fordon Bridge, too, they were proposed by the designer, but finally were not allowed. An example of recent date, taken from the details of the railway bridge over the Argen on the Lake of Constance**), is shown in figures 96, 143 and 144.

Fig. 143. Detail of bearing for crossgirder of the Argen Bridge. Longitudinal section of bridge.

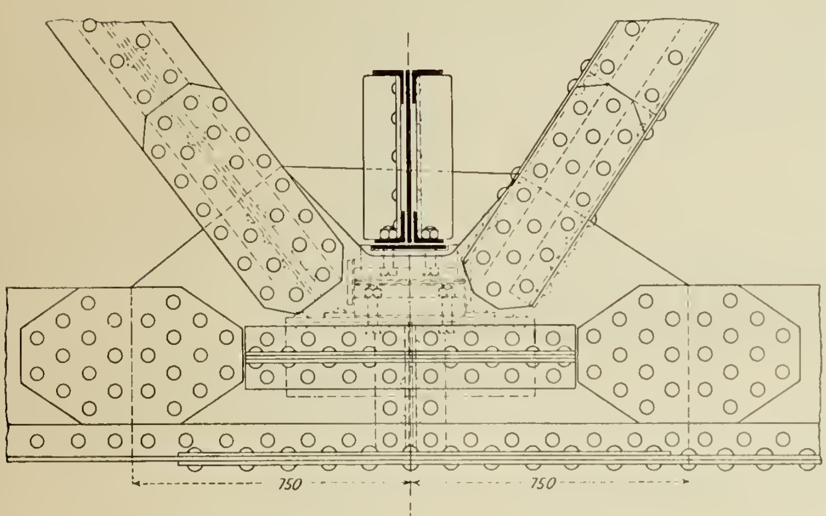
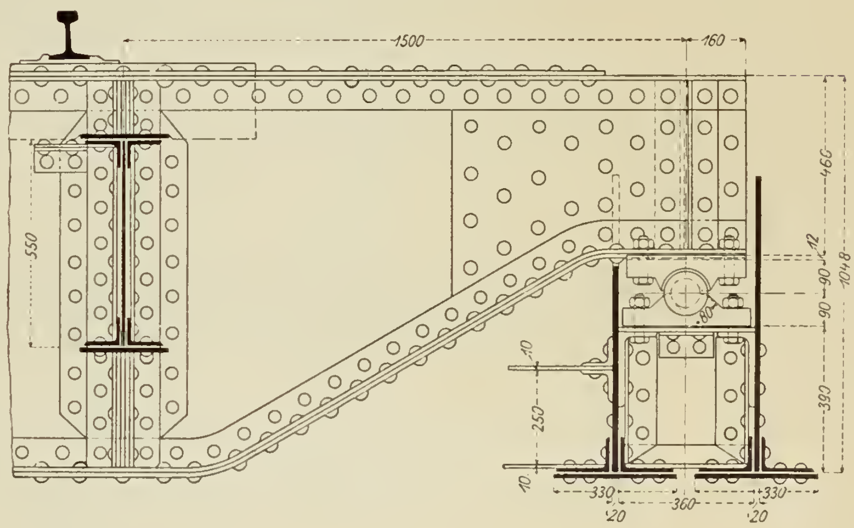


Fig. 144. Detail of bearing for crossgirder of the Argen Bridge. Cross section of bridge.



(Dimensions in millimetres.)

violence. No doubt the shortcomings of European bridges were exaggerated at the time, not only by the public, but even by men of the profession, being under the immediate influence of that calamity. If this was depressing to the people concerned, it cannot be denied that the ebullitions of the press and their effect on the official classes finally became the means of effecting some good. For since the Mönchenstein accident the problem of the *lateral stability* of iron bridges has begun to attract serious attention, and the danger of so-called *open bridges*, the Mönchenstein Bridge belonging to this type, has since been thoroughly discussed.

In case of open bridges it is of course absolutely necessary to design all their parts in a manner to form *one rigid structure;* this is best done by firmly rivetting up the platform with the maingirders in order to obtain sufficient lateral stiffness of the top flange. The case of through-bridges is entirely different, because the upper windbracing provided here is always sufficient to counteract any buckling tendency of the top flange. Moreover, it secures the vertical position of the maingirders in an efficient manner without the necessity of providing it with

Recently the principle referred to above of strictly separating main structure and platform, as far as their mutual mobility is concerned, has been more sharply accentuated in its application to real designs, chiefly in order to reduce the secondary strains in the maingirders (see page 45). If both are too firmly fixed together, the free deformation of each is inconveniently interfered with by the other, and the distribution of forces naturally becomes more complicated and confused. Being aware of these drawbacks, some designers were induced at an early date to provide the railbearers with moveable bearings on the crossgirders, or to make them act as cantilevers with a moveable piece inserted between them. The same end was to be attained by the moveable bearing of the crossgirder on the maingirders, already referred to. The whole of these expedients, however, did not really solve the problem in a satisfactory manner. This can apparently only be accomplished, without raising fresh difficulties, by entirely separating the platform from the parts forming

*) Constructed by the Gutehoffnungs Works.
**) Constructed by the Esslingen Works.

the main structure, the latter being at the same time designed in a manner conforming to this purpose. The resulting *"freely suspended or freely supported platform"* was first introduced by the Harkort Company by their design of a Rhine Bridge at Bonn, awarded a prize at the competition in 1894. Similar arrangements were shown in the designs of the same firm for the Railway Bridge at Worms, the Roadbridge over the Southern Elbe at Harburg and the Moselle Bridge at Trarbach, all of them being awarded prizes. Since then the principle of the freely suspended platform has been taken over, with some modification of detail, by other works, as for instance the Nuremberg Company, when building the Bridge over the Southern Elbe at Harburg (see fig. 47). The construction in question proves to be particularly simple in case of *tied arches* with suspended platform, as shown in figures 145 to 148.

The freely moveable part of the platform always extends the whole length of the tension member, because it is chiefly the latter, which in case of a firm connection between both, by its extension would affect the movements are strengthened for the purpose. The two tension bars z of the arch form the flanges of the windbracing, otherwise consisting of crossed diagonals, between which the crossgirders, suspended from the arch, are freely swinging (see figures 145c and 146c). In this manner the platform transmits its windpressure to the lower windbracing at the centre of the nodes, without being in the least interfered with as regards its own mobility. In order to transmit the *brake power* from the platform to the main structure in a longitudinal direction, it is sufficient to secure the central or (in case of an odd number of panels) the two central crossgirders in their relative position to the main structure. This is easiest done by means of small brackets, which prevent any displacement of the crossgirder (or of the two crossgirders) in the direction of the maingirders, without causing any strain themselves. In case of railway bridges the brake power is to be provided for by inserting a special bracing between the platform and the central panels of the windbracing, at the same time adding a strong connection with the tension members, as shown in fig. 145c at 7. For obvious reasons these additional

Fig. 145. Railway Bridge over the Rhine at Worms.

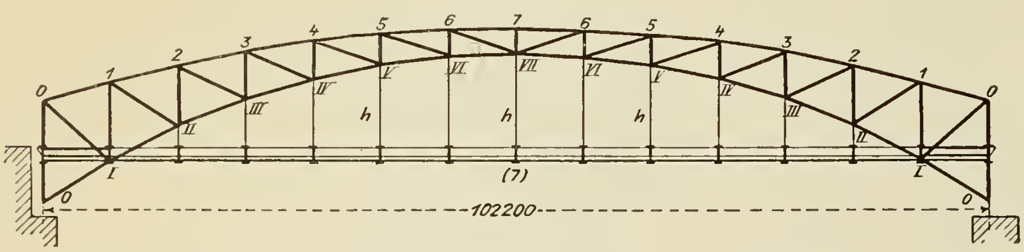


Fig. 145a. Sections.

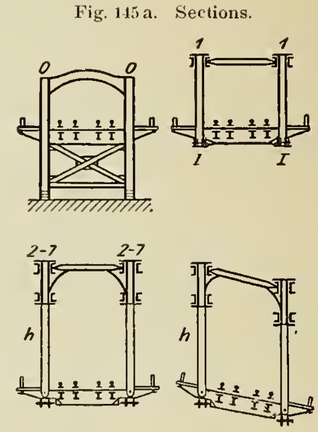


Fig. 145b. Upper windbracing.

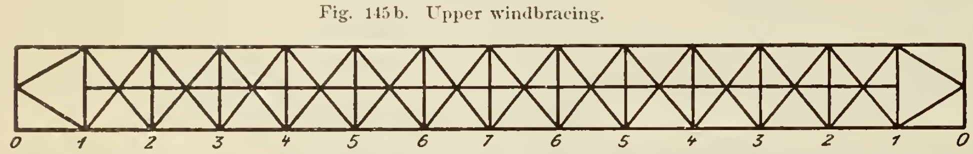
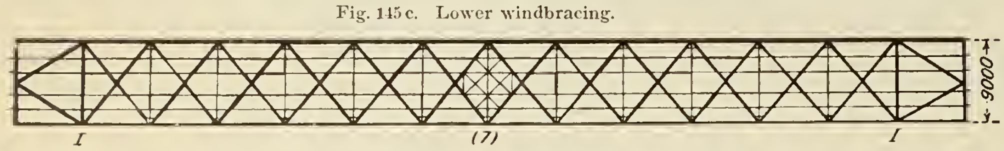


Fig. 145c. Lower windbracing.



The main structure is shown in *thick* lines, the moveable platform in *thin* lines.

of the platform. Accordingly in case of the Railway Bridge at Worms (see fig. 145) the platform has been cut for the purpose of dilatation at the nodes marked I and I, in case of the Trarbach Bridge (see fig. 146) at the points 0 and 0. In the former instance, therefore, the platform of the end panels has been firmly connected to the main structure.

Though main structure and platform are to be kept independent of each other, nevertheless on account of the windforces and the action of the brake a certain condition in the relation between them has to be observed, viz. that the platform laterally as well as longitudinally should be secured in its relative position to the main structure, in a manner however, that no secondary strains and mutual interference can occur. This condition is realized by the Harkort Company in a way similar to that already proposed by Winkler in his lectures in 1884[89]).

The transmission of the windforces, acting on the platform and on the rolling stock carried by it, to the lower windbracing fixed to the main structure, is effected by means of the crossgirders (see figures 147 and 148). For this purpose the latter at their bottom flange are provided with projections c, designed as vertical bearings butting against the cornerplates a of the lower windbracing, which stiffening parts would be superfluous in the case of roadbridges (see fig. 146c).

The tension members z of the main structure are placed below the ends of the crossgirders, from which they are suspended in a hinge-like manner (see figures 147 and 148); consequently any relative movements between tension member and platform, taking place between the fixed points at the middle and at the ends of the bridge, are not interfered with in the least.

In order to reduce the bending moments occuring at the points of support of the crossgirders, either in consequence of the deflection of the latter or of any irregular deformation of the maingirders (more particularly in case of bridges carrying a double line of railway), the crossgirders should be suspended in as flexible a manner as possible. At the Worms Railway Bridge (see fig. 147) ordinary pins have been used for this purpose; in case of roadbridges, where as a rule the traffic is uniformly distributed over the whole width, the connection may be rivetted up in the ordinary way, provided the suspenders h are designed with a section possessing a small moment of inertia only, like those of the Moselle Bridge at Trarbach (see fig. 148).

Fig. 146. Roadbridge over the Moselle at Trarbach—Traben. (Dimensions in millimetres.)

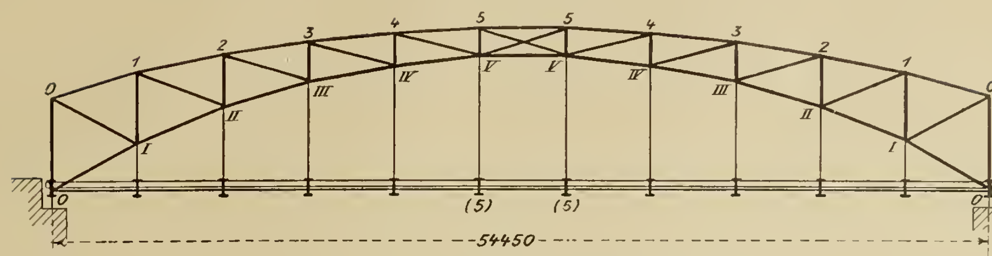


Fig. 146 a. Sections.

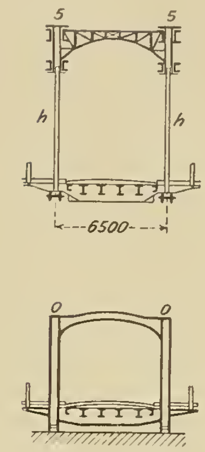


Fig. 146 b. Upper windbracing.

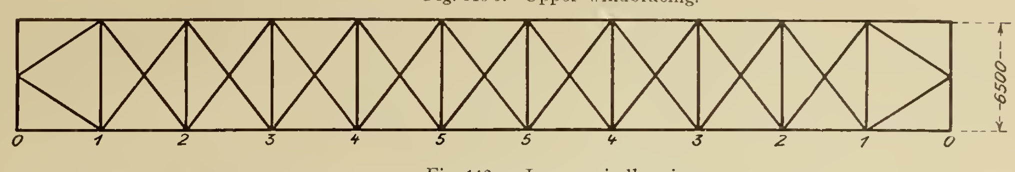
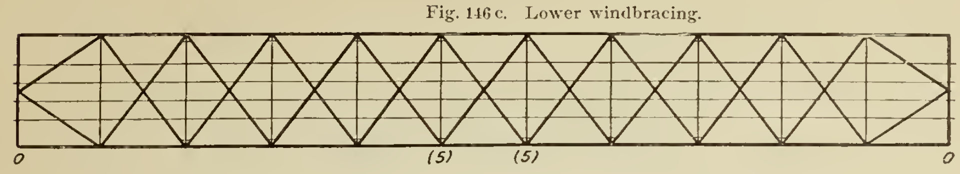


Fig. 146 c. Lower windbracing.



The main structure is shown in *thick* lines, the moveable platform in *thin* lines.

Fig. 147. Railway Bridge over the Rhine at Worms.

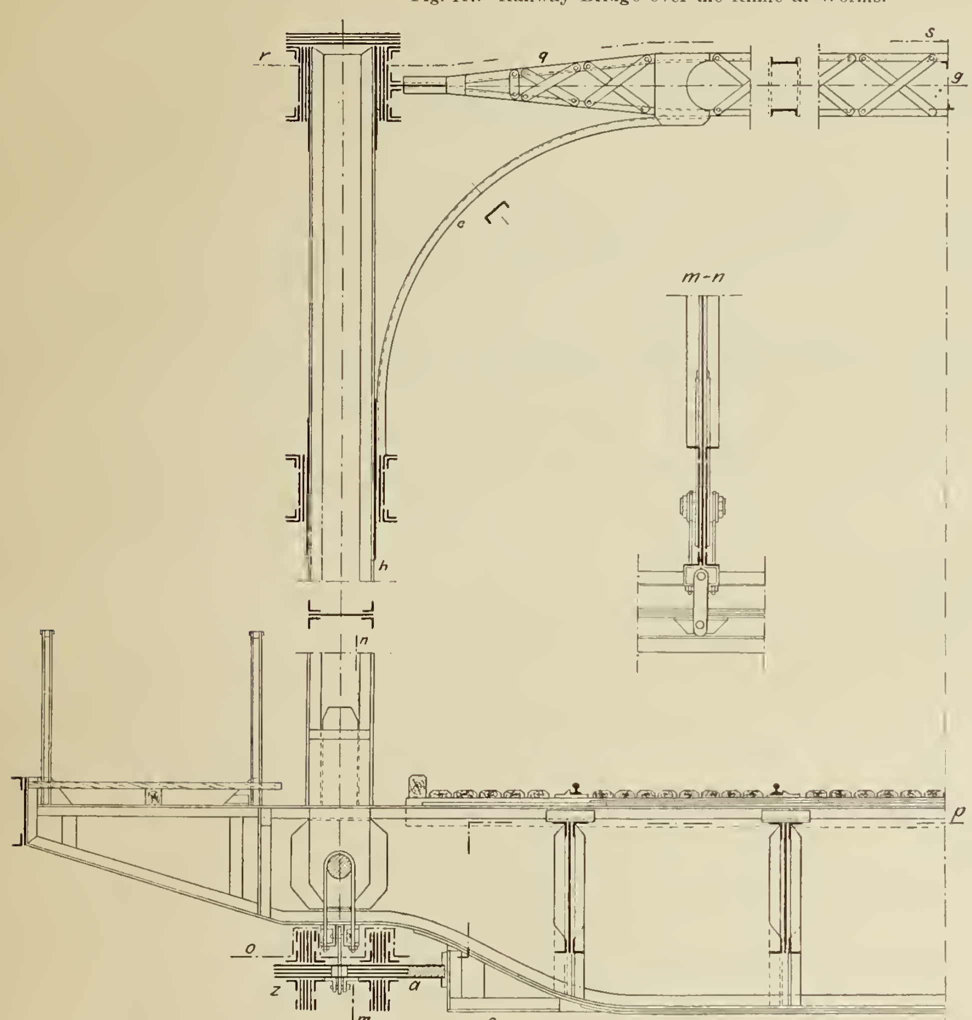


Fig. 148. Roadbridge over the Moselle at Trarbach—Traben.

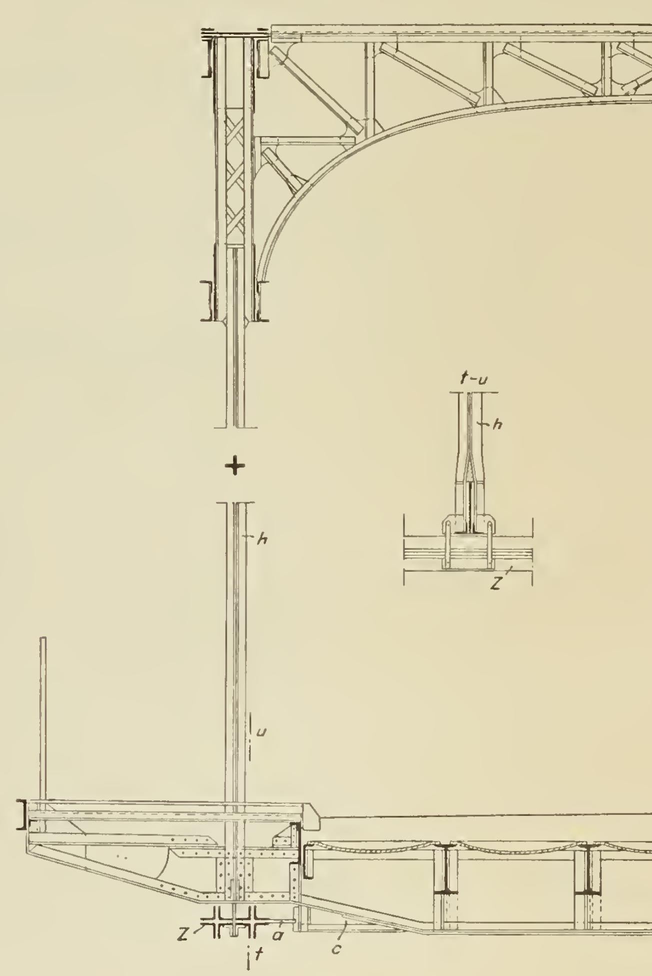


Fig. 147 a. Plan and section o—p.

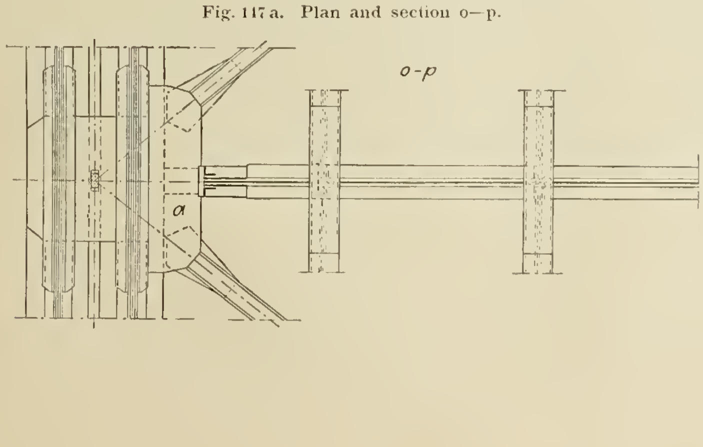


Fig. 149.

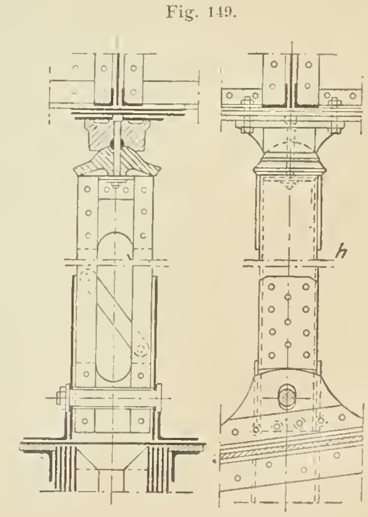


Fig. 149. Rocker verticals of the Roadbridge over the Rhine at Worms (design).

The advantages of the freely suspended platform, as described above, are particularly conspicuous in case of double track railway bridges, because the crossframes of their main structure can freely assume the rhombic form indicated in fig. 145a, resulting from unequal deflections of the two maingirders, without the latter leaving their vertical position. In order to make this possible, the connection between windbracing and main structure should be a *flexible* one. In the examples shown in figures 147 and 148 this connection, therefore, merely consists of horizontal cornerplates, possessing a sufficient degree of elasticity in a vertical direction to permit small movements, without giving rise to bending moments of any magnitude. For roadbridges with a more uniformly distributed load and for single track railway bridges the point in question is of less moment, because any considerable difference in the deflection of the two maingirders and consequent rhombic distortion of the bridge section either does not take place at all or at rare intervals only. In these cases, therefore, the upper crossbars q can be made stiffer, provided the suspenders h are sufficiently flexible, like those of the Trarbach Bridge (see fig. 148), to offer no considerable resistance to bending.

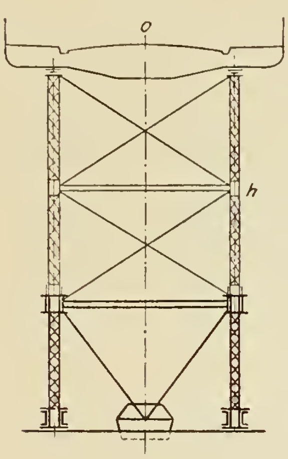
An example showing, how the platform, being on top, can be made a "freely supported" one instead of "freely suspended", is offered by the design of the Roadbridge at Worms, awarded a prize at the competition in 1895 and illustrated in figures 149 to 151. In this instance the platform loads are transmitted to the main structure by the struts h, provided with crossframes, and fixed at the bottom to the upper cornerplates of the maingirders by means of pins, allowing them to move freely in a longitudinal direction, while on top they carry the crossgirders of the platform on ball bearings (see fig. 149). An exception is only formed by the struts o—o over the main bearings (see fig. 150a), because, being very long and having a very small moment of inertia within their plane of oscillation, they offer but little resistance to bending in any case. At the crown of the main arches the platform is rivetted up with the main structure (see fig. 150). The relative movements between platform and maingirders consequently take place from the middle towards both ends of the span, without, however, the struts h undergoing any deformation by bending or being affected by secondary strains.

The upper windbracing, forming part of the platform and terminating in a point, bears immediately against the piers, which for this purpose are provided with special bearings, allowing a longitudinal, but no lateral movement of the windbracing as well as the platform (see fig. 150b). In the same manner the crossframes, lying in the plane of the end verticals, at o, together with the lower arched windbracing, have their triangular termination over the piers (see figures 150c and 150a), where they are anchored down to a joint bearing. Any metallic connection between the points of support of the main arches has been intentionally omitted in order to prevent the action of lateral forces on the main bearings, which would tend to affect their firm connection with the masonry (see fig. 150a).

Some further details of recently built bridges will be found in the Appendix, describing *the exhibition of German bridge works at Paris*. Details of *hinges* for archbridges are discussed by *Backhaus* in the interesting paper marked[88]) in the table of literary references.

Fig. 150. Roadbridge over the Rhine at Worms (Design).

Fig. 150a. Section o.



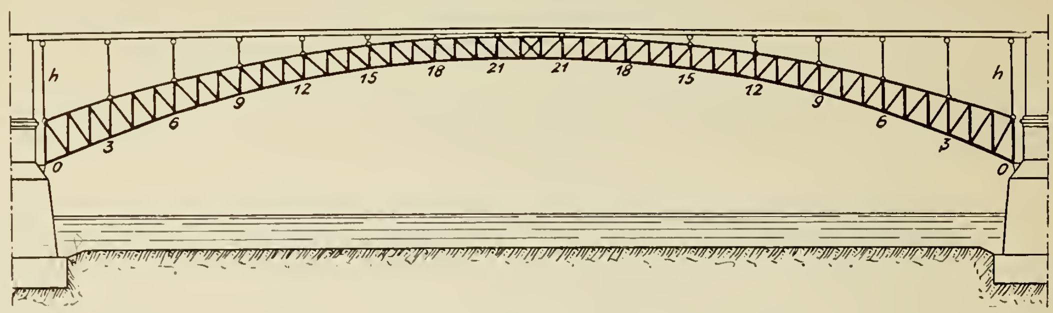


Fig. 150b. Upper windbracing.

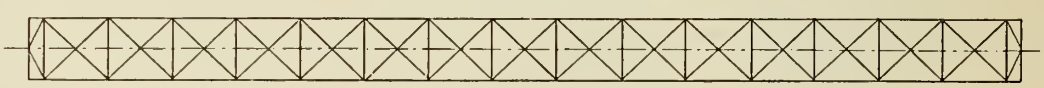


Fig. 150c. Lower windbracing.

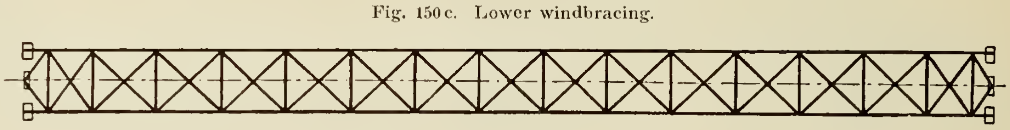
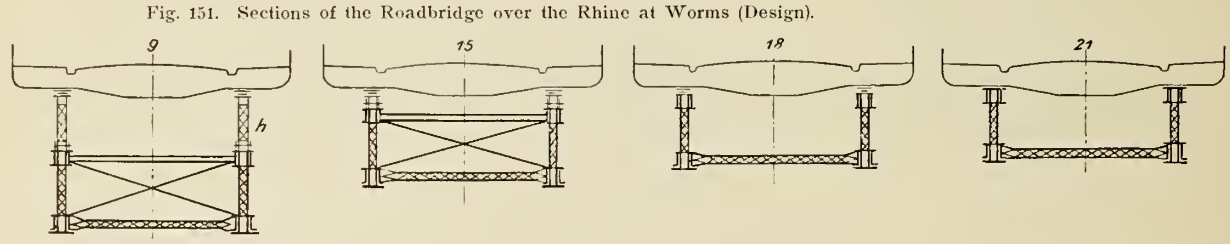


Fig. 151. Sections of the Roadbridge over the Rhine at Worms (Design).

The main structure is shown in *thick* lines, the moveable platform in *thin* lines.



IV.

Bridge-building companies and their work.

23. GENERAL NOTES. During the early stages of iron construction German buildings of any importance almost invariably were put up by the public building departments on their own account. No bridge works were in existence at that time. The manufacture of smaller structures was as a rule confided to the better class of engine factories, while in case of larger bridges private firms often used to erect special workshops near the site, as happened for instance at the building of the old bridges at Dirschau and Cologne. The old railway bridges over the Vistula and the Nogat are typical examples of this mode of proceeding.

In July 1847, when in consequence of political and financial troubles the works were suddenly stopped by royal order, fully 7700 workmen were employed at Dirschau, including the dikes and the Nogat cutting at Montau Point. After a good deal of property had been acquired, the first sod for the building of the great Vistula Bridge had been turned on September 8, 1845, and numerous edifices, including an office for the building commission, as well as some workmen's barracks, had either been finished or were in course of erection. In addition many implements required for the erection had been procured or ordered, and contracts had been entered into for the supply of stone, timber and other materials. Large brick-works with 16 kilns and 9 drying sheds had been established by the department near Knieban village, where 200 workmen were employed and 4 million bricks, half of them still unburnt, were in stock. The greater part of the plant for making cement, mortar and concrete, as well as the repairing shops had almost been finished. Moreover, in order to ensure as far as possible the speedy erection of the iron superstructure by the department, an engine factory with foundry had already been put up and was worked *by a private company* at Dirschau, while a building containing a forge and other workshops was being erected at Dirschau station. Just at the moment when the members of the building commission were assembled to be present at the first casting, the peremptory order arrived to stop the whole of the works, and the feeling of dismay that took possession of these men, prepared to do their very best to advance the great work, can be well imagined. The involuntary interval lasted for fully three years. On July 27, 1851, the king himself laid the foundation stone at the Dirschau abutment, and on October 20, 1855, Lentze was enabled to inform by wire *von der Heydt*, the minister of finances, that the scaffolding of the first two spans had been successfully removed. On October 12, 1857, the first railway train passed over the bridge[60]).

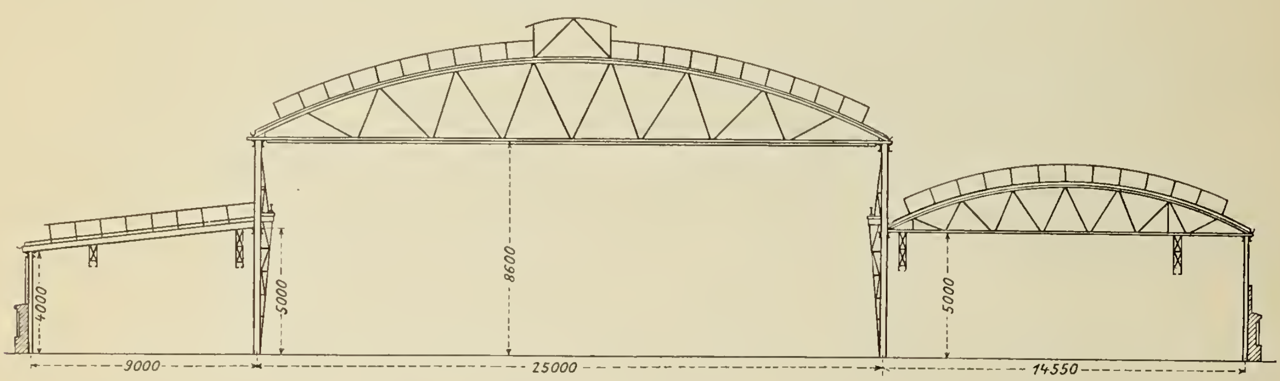
The great merits of *Schinz*, the eminent theorist, who had charge of the theoretical as well as the constructive part of the designs, have already been duly acknowledged on page 54. In addition the name of *H. W. Krüger* of Potsdam (1817—1876) deserves to be mentioned, who was the manager of the engine works referred to, established by himself, where he made the whole of the ironwork required for the bridge, including a number of engines, being ably assisted by *Rintelen*, an engineer, and *Franck*, an overseer. *Schwahn* (at a later period chief manager to the Mecklenburg Friedrich-Franz Railway Company) was in special charge of the building operations. Besides many younger men of ability had devoted themselves to the great work in hand, among whom the following may be mentioned: *Malberg*, who before that time had built the chainbridge at Mülheim-on-the-Ruhr (see page 76), and the engineers, since departed, *Rhode*, *Sternberg*, *Bendel* and *Böhmer*, the first three of whom later on had occasion to distinguish themselves as bridge designers: Rohde at the old Hamburg Elbe Bridges, Sternberg as a professor at the technical college, Karlsruhe, and Bendel as chief draughtsman to the Linksrheinische Railway at Cologne. Moreover, among the younger assistants engaged at the works some well-known names, like *Niemann*, *Mellin*, *A. Wiebe* and *Dirksen*, are to be met with. *Lohse*, the designer of the old Railway Bridges at Cologne and Hamburg, directed the building operations at the Marienburg Bridge[60]).

The old Cologne Bridge[90]), too, has been constructed by engineers employed by the Rhenish Railway Company. During the winter of 1855—56 special workshops were erected for making the ironwork, and the machine-tools required were either procured from Dirschau or imported from England. The fact that, as far as known, at the

erection of the Cologne Bridge the first experiments were made and reported on by *Lohse* concerning the resistance of iron bars against buckling, deserves particular notice[90]).

The larger works already existing in Germany at that time, i. e. about the middle of the fifties, were mostly concerned in the manufacture of iron bridges in an incidental manner only. Their main activity was directed to other branches of engineering. The first among North German works, that turned its particular attention to bridge construction, was that of *Joh. Caspar Harkort* at Harkorten near Haspe. Founded in 1846, it has since developed into the present *Harkort Company.* The oldest South German establishment is probably represented by the ironworks of *Benkiser Brothers* at Pforzheim, the foundation of which dates back as far as 1752[91]). *Aug. Benkiser,* a designer of unusual ability and routine, soon succeeded in becoming very prominent as a bridge builder. By referring to Tables I to IV it will be seen that a large number of important South German iron bridges of older date was constructed at the Pforzheim works, among them the Rhine Bridges at Kehl, Basle, Mannheim, Germersheim and Mayence, the Obermain Bridge at Frankfort and many others. In addition many important structures were sent abroad. Since 1888 the bridge department of the works has been discontinued.

Fig. 152. Section of new bridge-workshops of the Gutehoffnungshütte at Sterkrade. (Dimensions in millimetres.)



The second oldest bridge works in South Germany are represented by the Engine Factory of *Johann Friedrich Klett* at Nuremberg, founded by him in 1837 with the assistance of three English engineers. After a number of transformations is was finally merged into the present United Augsburg and Nuremberg Companies. The following establishments were subsequently founded: In Württemberg, the works of *Decker Brothers* at Cannstadt, the present *Esslingen* Engine Works; in Prussia, the Bridge Works of the *Gutehoffnungshütte* at Sterkrade in 1864, and the *Union Works* at Dortmund in 1872; in Saxony, the *Königin-Marien-Hütte* near Kainsdorf and the *Lauchhammer Works.*

It has been already described in the preceding pages, how the bridge-building companies named above in the course of time have advanced the art of bridge construction in all its branches, the Tables I to VI containing a summary of the work done. In addition it was mentioned that recently, in consequence of the now prevailing institution of public tenders, the working out of detailed designs has gradually become a monopoly, well justified under the circumstances prevailing in Germany, of the bridge companies (see page 40). At the same time it has been pointed out that the building departments would be well advised in contenting themselves with preparing the scheme and the preliminary design, or in case of a competition (either limited, public or private) with deciding about the plan best fitted for execution, but for the rest to leave everything to a trustworthy firm of bridge builders, only reserving to themselves the right of carefully supervising all operations taking place within the yard or at the erection. The great German bridge companies at present are all provided with an excellent staff of officials trained theoretically and practically, with whom a single engineer can no longer hope to compete successfully. This is conclusively proved by the results of recent bridge competitions, the prizes invariably going to the larger firms. The latter as a rule are working together with an architect (see page 41) and with a firm of builders for the pier work. It is only natural that in the course of time the principal branches of bridge construction should have grown into special lines of business, the firms contracting for *pier foundations* being among the most important ones. The oldest German establishment of this kind, being a company of world-wide fame attending to all branches of engineering, is represented by the firm of *Ph. Holzmann & Co., Ld.,* of Frankfort-on-Main, the foundation of which dates back to 1856.

As in all other departments of industrial life, "division of labour" has become the dominating principle in bridge building also. Many a man would wish to have back the "good old times", when by the incessant haste and pressure of the hour he is compelled to rush through his work, without having time to attend to all its details with the painstaking care characteristic of old times.

The following paragraphs contain some particulars concerning the organisation and production of those bridge companies, by whose orders the present work was published, the firms in question being arranged alphabetically. A description of the exhibition of German bridge works at Paris will be found in the Appendix.

24. THE ESSLINGEN ENGINE WORKS (MASCHINENFABRIK ESSLINGEN) AT ESSLINGEN. These works have been founded more than fifty years ago, chiefly for the purpose of building locomotives and railway cars, this branch of engineering still forming the most important part of the business done. Soon after its foundation the building of steam engines as well as bridges and other ironwork was added, and with regard to iron bridges it will be seen from Table I that the Esslingen

Works have taken part in the construction of the oldest bridges existing in Germany. At an early period, when the demand of the kingdom of Württemberg alone was insufficient to keep the works going, many bridges, etc., have been made for the Austro-Hungarian and Swiss Railways, also, after 1870, for the Imperial Railways of Alsace-Lorraine and other German lines (comp. Tables II to VI). In 1872 the Esslingen Works supplied the bridges for the Baden Black Forest Railway Hausach-Triberg-Villingen, in 1876 those for the Tessin Valley lines of the Gotthard Railway, in 1881 several bridges and two of the largest station roofs of the Berlin Metropolitan Railway, viz. those of the Silesian and the Alexanderplatz Stations, in 1883 a large bridge, including a swing span, over theMasnedsund in Denmark. In addition the works have supplied a large number of turntables, sliding platforms, travelling cranes, trestle cranes, pontoon, iron boats, cement silos, panorama buildings, station roofs and other structures of a similar kind. During the last ten years, in consequence of the pronounced revival of railway building in Württemberg, the works have been fully employed by the orders for iron structures emanating from the state, the cities and private firms of that country, amounting on an average to about 2000 tons a year.

At present the Esslingen Company in their works at *Esslingen* and their branches at *Kannstadt* and *Saronno* employ over 2600 workmen and officials. The average output of 2000 tons a year, stated above, is derived from the total production of the Kannstadt and Esslingen Works as follows:

	30 000 tons	of railway bridges for Württemberg
	10 000 -	- - - for other countries
	15 000 -	- roadbridges
	15 000 -	- other iron structures
Total	70 000 tons,	i. e. about 2000 tons a year.

Fig. 153. Interior view of new bridge-workshops of the Gutehoffnungshütte at Sterkrade.

In addition the works have produced 3100 locomotives, 8000 railway cars, steam engines of together 26 200 H. P., steam boilers of a total heating surface of 36 500 square metres (393 000 square feet), further pump-works and ice-making machines; 960 dynamos and 1500 electro-motors of together 21 200 Kilo-Watt.

Besides ropeways and cable tramways *cog-wheel-locomotives* form a specialty of the firm, 90 of the latter having already been supplied. A locomotive of this kind will be on view at the exhibition of German locomotive works at Paris-Vincennes.

At the public bridge competitions, taking place during the last ten years, the firm was awarded the following prizes:

1894 Danube Bridge at Budapest (see fig. 55)	First prize among 76 designs from all countries.
1895 Rhine Bridge at Bonn (cable bridge, see fig. 56)	Second prize.
1895 Po Bridge at Turin	First prize awarded among 21 designs.
1896 Rhine Bridges at Worms a) Roadbridge	Third prize.
b) Railway Bridge	Third prize.
1897 Elbe Bridge at Harburg	Fourth prize.
1897 Three Dreisam Bridges at Freiburg i./B.	A first prize and two second prizes.
1898 Swingbridge over the harbour at Libau, Russia	First prize awarded.

Oberbaurath Professor *Gross* acts as general manager to the company, while the bridge department is under the management of Baurath *Kübler*.

25. THE GUTEHOFFNUNGS WORKS (GUTEHOFFNUNGSHÜTTE). In the report published by the „*Aktienverein für Bergbau und Hüttenbetrieb*" (Mining and Metallurgical Company, Ld.) on the occasion of its 25[th] anniversary, it can be read, how the present giant establishment originated in the former mining association, later changed into a trading company, of *Jacobi*, *Haniel* and *Huyssen* at Gutehoffnungshütte, Sterkrade. On January 1, 1873, the latter firm was bought out by the present limited company, which since that time owns the whole of the extensive works, foundries, rolling mills, coal- and other mines, quarries, forges, brickworks (at Styrum), etc.

The *Antony Works,* founded in 1757, are the oldest branch of the firm. On May 3, 1781, Frederick the Great gave his assent to the erection of the original works, viz. the foundry called *Gutehoffnungshütte* at Sterkrade, which on April 12, 1800, went into the possession of Mrs. *Krupp,* the grandmother of *Friedrich Krupp.* Eight years later is was resold to *Heinrich Huyssen* of Essen, after an engine factory had been added to the foundry. In 1819 the first *steam engine* was received, in 1839 the *boiler works* were added, in 1853 the *hammer-forge,* and in 1864 a special *bridge department* (see figures 152 and 153). The fine new *foundry buildings* (see fig. 154) deserve particular attention.

At present the works consist of the following departments: The *Bridge Works* at Sterkrade, for particulars of which see below; the *Engine Factory* at Sterkrade, comprising the engine workshops proper, chiefly used for the manufacture of plant for rolling mills and smelting works, an iron- and metal-foundry, a steel casting shop, a squeezer, a steam-hammer forge and steam boiler works; the *Oberhausen Rolling Mill* at Oberhausen with 18 puddling-furnaces,

Fig. 154. New foundry of the Gutehoffnungshütte at Sterkrade.

8 welding-furnaces, 8 heating-furnaces, 11 roll-trains, 58 steam engines and 7 steam hammers; *the Neu Oberhausen Steelworks* at Oberhausen with a Thomas and Martin steelwork, containing 4 converters and 4 Siemens-Martin furnaces, further works producing axles, tyres and sets of wheels, 8 heating-furnaces, 10 roll-trains, 102 steam engines and 6 steam hammers; the *Oberhausen Smelting Works* at Oberhausen with 9 blast furnaces, 26 Cowper's hot-blast ovens, 451 coke-ovens and 95 steam engines; the *Oberhausen Colliery* with the pits Oberhausen I and II at Oberhausen, the Osterfeld pit at Osterfeld, the Hugo pit at Holten and the Sterkrade pit at Sterkrade, the Ludwig mine at Rellinghausen near Essen-on-the-Ruhr. The Neu-Essen mill, a fire-brick works.

The iron mines owned by the Gutehoffnungshütte, Ld., situated in Nassau, Siegen, Bavaria, Lorraine, Luxemburg etc., comprise mining rights extending over an area of 1900 square kilometres (745 square miles). The company owns grounds to the extent of about 1000 hectars (2470 acres). The whole of the engine power used amounts to about 40000 H.P. At present the works employ over 13 000 officials and workmen; the share capital amounts to 18 000 000 Marks (£ 900 000).

The workshops of the bridge department at present cover a roofed-in area of roughly 20 000 square metres (24 000 square yards), including a hall of three naves, built in 1893, 225 metres (738 feet) long and 48 metres (158 feet) wide (see figures 152 and 153).

The central nave, 25 metres (82 feet) wide, of this new building, used as an *erecting shop,* is provided with two electric overhead travellers of a carrying capacity of 10 tons each, while the side naves contain the machine-tools, also worked by electricity. In addition to the narrow-gauge tramways referred to, the side halls are provided with a system of *aerial tramways,* which by means of turntables and transverse connections allow easy communication between the different lines and with the central nave.

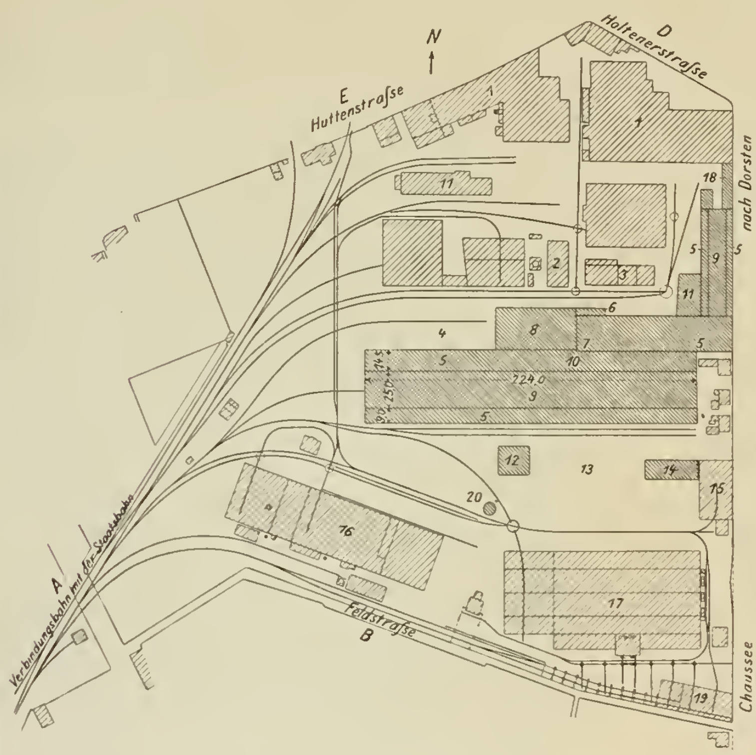
It will be seen from the plan, fig. 155, that besides the large new building just described there is a bridge workshop of older date, used at present chiefly for mining-ironwork and other small structures of a similar kind. Adjoining this there is another shed containing a number of additional machine-tools as well as 14 hearths with a small steam hammer and the plant for straightening and edging the rolled bars.

The rolled material is drawn almost exclusively from the company's own works at Oberhausen, being carried (as shown in fig. 155) by the State Railway and a loop line into the stock yard, the latter being provided with a system of narrow-gauge tramways. The whole of the ordinary-gauge lines near the bridge works have been adapted to accommodate trolleys by adding a special rail in the middle.

12 different straightening and 2 edging machines are provided, two of the former being worked by hydraulic pressure. In addition another large hydrostatic press of 500 tons is used for bending bars, etc. The material is then carried into the adjoining workshops, where it is cut to measure, planed or shaped, as far as this can be done at this stage of manufacture. If necessary, the material is taken to the adjoining forge.

After the centre lines of all bars of the structure have been marked out on the frames, and the rivet holes fixed and marked with the centre-punch accordingly, the pieces are further manipulated in the side halls, the rivet-holes being drilled with a diameter slightly smaller than that of the rivets. After this the pieces are taken back to the erecting room and put together by means of bolts to form the complete structure. The holes for rivets to be inserted at the works are then rimered, partly by machine, partly by hand, and the rivets put in, if possible, by hydraulic rivetters. In case of rivets to be inserted at the erection, the holes, too, are rimered there.

Fig. 155. Plan of the Gutehoffnungs Works' Bridge Department at Sterkrade. Scale 1:5000.



1. Mechanical workshop.
2. Boiler house.
3. Electric central station.
4. Stock yard for rolled iron.
5. Machine-tools.
6. Hydrostatic press of 500 tons.
7. Forge.
8. Shed for straightening bars.
9. Erecting shop.
10. Rivetting machines.
11. Warehouse.
12. Pickling shed.
13. Stock yard for implements used at erection.
14. Shed for implements used at erection.
15. Template shop.
16. Steel-casting shop.
17. Foundry.
18. Offices.
19. Shed for washing moulding-sand.
20. W. C.

If any part of the structure has to be made several times over, as for instance the two maingirders of a bridge, the first girder, after having been put together, is taken to pieces again, for the latter to serve as templates to the second. The girders, however, made according to templates, nevertheless are erected complete in the same manner, in order to make sure of all parts fitting together and to be able to rimer all rivetholes in one operation. Before being joined together the separate pieces are thoroughly cleansed from rust, either by machine or by pickling with acid.

The Bridge Department since 1887 has been under the management of Professor *Krohn.* Its output at present amounts to about 18 000 tons a year, 1200 workmen being employed. The iron bridges built by the Gutehoffnungs Works have been repeatedly referred to in the preceding chapters, being moreover enumerated in Tables II to VI. The bridge designs exhibited by the firm at Paris are briefly described in the Appendix.

Among the structures erected *abroad* the following are the more prominent ones:

Norway: The Lo, Voldoe, Landwerks, Moelven, Kwarsten and Paulen Bridges of the Norwegian State Railways.

Russia: The Railway Bridges over the Bug, the Bystrcyca, the Wkra and the Swider;

Finland: 30 bridges for the Department of Roads and Hydraulic Works, including a swingbridge; in addition 27 bridges for the Railway Department and 5 bridges for the Nykarleby Railway;

Fig. 156. Gutehoffnungshütte. Hoisting-frame and building for the Zollverein Mine. 1895.

Denmark: Roadbrige at Copenhagen;

Holland: 7 bridges for the Dutch State Railways; 1 swingbridge for the City Railway at Rotterdam; 1 bridge over the Rhine at Reenen and 2 bridges over the Merwede Canal at Utrecht; a roadbridge over the Yssel for the city of Kampen;

Switzerland: 1 archbridge over the Aare for the city of Berne; 140 bridges for the first line of rails of the Gotthard Railway; the Langenstrasse Bridge as well as 2 Sihl Bridges for Zürich; 2 bridges at Wintherthur for the Swiss North Eastern Railway and a bridge for the South Eastern Railway;

Roumania: 30 railway- and roadbridges for the Ministries of Public Works and of War, and for the Roumanian State Railways;

Greece: About 300 railway- and roadbridges for the Greek Railways;

Dutch India (Java and Sumatra): About 40 railway- and roadbridges for the State Railways and the Department of Public Works of Java and Sumatra, in addition 7 bridges for the Dutch Indian Railway Company and about 80 smaller bridges for the Kediri Steam-Tramway Company;

Japan: 1 bridge over the Ghitosche;

China: A large number of bridges for the Shantung Railway;

Egypt: 12 railway- and roadbridges (including a swingbridge) for Upper and Lower Egypt;

South African Republic (Transvaal): 12 bridges for the Netherlands South African Railway Company;

Argentine Republic: 1 bridge in Tucuman and 1 roadbridge in Rosario;

Venezuela: About 35 bridges for the Great Venezuela Railway, Carracas and Valencia line;

Columbia (South America): 1 railway archbridge over the Magdalen River;

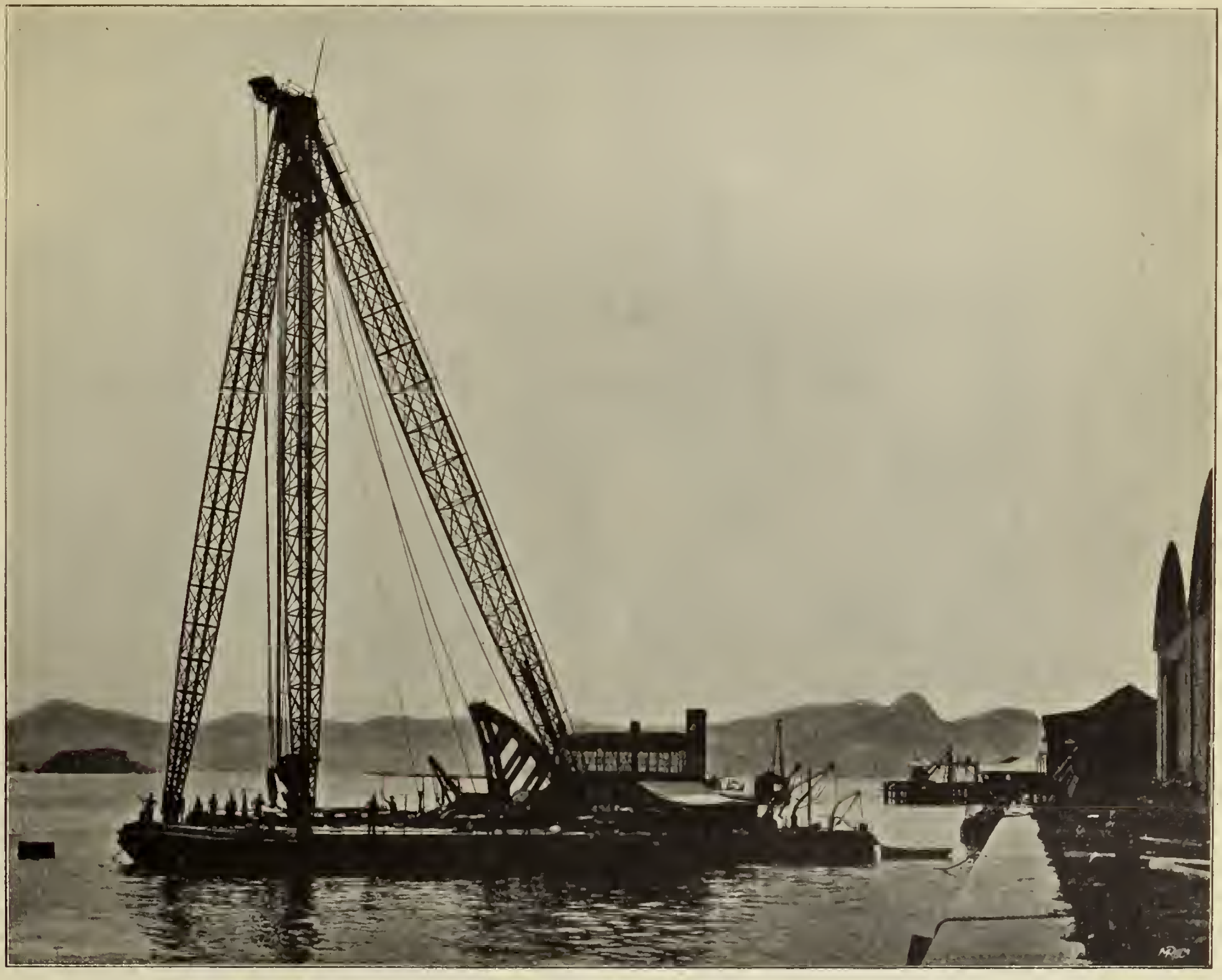
Brazil: About 75 railway bridges for the Brazilian Central Railway, the Western Railway, the Itapemèrin Railway, the Northern Railway, the Southern Railway de Espirito Santo, and for private firms, 1 roadbridge for the city of Cacheiro de Itapemèrin and 1 roadbridge at Lorena.

The Bridge Department of the Gutehoffnungs Works in addition supplies ironwork required for other branches of engineering on a large scale, the most important line being the supply of *mining plant,* including for instance: Drawing-frames with shaft houses; plant for separating and dressing ores; buildings for hoisting- and draining-engines; workshops, boilerhouses, buddles and benzol works; transport stages, hauling-frames, engine-beams, pump-gear, etc.

For the whole of these buildings (an example of which, representing the *hoisting-frame and building for the Zollverein Mine,* is shown in fig. 156) the firm makes use of a special roof construction, the outer skin of which consists of a layer of 4 to 5 centimetres ($1^1/_2$ to 2 inches) of *plaster-lime,* which, being of considerable carrying power, is put on the finished iron structure by a special process, perfected by the firm. Since 1887 the company has supplied over 190 000 square metres (227 000 square yards) of these roofs. Another important line of business is represented by the erection of *large iron halls and roofs,* as for instance those of the railway stations at Bonn, Deutz, Düsseldorf, Elberfeld, Frankfort-on-Main and that of the Anhalt Station at Berlin. The firm has also supplied *floating docks* to the Imperial Dockyards at Danzig, Wilhelmshaven and Kiel, to Messrs. Blohm & Voss of Hamburg, to the Vulkan Works at Stettin and others, further *floating cranes and sheers* of a carrying power of 40 tons each for Bremen and Ruhrort, of 100 tons for Kiel, etc., an example being shown in fig. 157. This structure, carrying 80 tons, was handed over in full working condition to the port authorities of Rio de Janeiro.

Among large iron structures, sent and erected abroad by the Bridge Department of the Gutehoffnungs Works, the following may be mentioned: Warehouses, hangars, landing sheds for Holland, Java, Asia Minor, Roumania and Siam. Factories for Sweden, Norway, Denmark, the Argentine Republic and Java; the extensive buildings, blast furnace plant, transport stages and other iron structures required for the Imperial Steel Works at Yawatamura in Japan. Shaft-frames and -houses for Chinese mines; coal elevators for Denmark (Copenhagen). Station roofs and locomotive sheds for Switzerland and Egypt; roof over the Central Railway Station at Amsterdam; the iron structure of a theatre at Rotterdam; wharf sheds at Amsterdam; exhibition building at Chicago for the firm of Friedrich Krupp; lock gates for Egypt.

Fig. 157. Gutehoffnungshütte. 80 ton - Floating Sheers for Rio Janeiro. 1897.



26. THE HARKORT COMPANY (GESELLSCHAFT HARKORT) AT DUISBURG. In 1846 *Joh. Caspar Harkort* (1816—1896) established bridge-building works at Harkorten near Haspe, from which numerous smaller bridges were supplied during the fourties, as for instance the Wupper Bridge

near Rittershausen, mentioned on page 52, followed during the fifties by some more prominent structures (see Table I). Towards the beginning of the sixties Harkort, in order to be able to take larger orders, built new works bordering on the Rhine at Duisburg, which up to 1872, when they were taken over by the present Harkort Company, have produced a large number of important German bridges (see Table II). In addition some railway bridges for foreign countries were built there during the sixties, like the Yssel Bridge near Zütphen, in the construction of which the Cologne Engine Factory (Kölnische Maschinenbau-Anstalt) at Cologne took part, and in 1866 the well-known Leck Bridge near Kuilenburg (see fig. 30), which for a long period had the widest span of any bridge in Europe, viz. 154,4 metres (507 feet).

In 1872 Harkort sold the works to the *"Aktiengesellschaft für Eisenindustrie und Brückenbau", vormals Joh. Caspar Harkort in Duisburg* (The Iron- and Bridge Company, Ld., late Joh. Caspar Harkort, at Duisburg). This joint-stock Company began by enlarging the works to a considerable extent, adding a rolling mill and a wagon factory, as well as a *department for pneumatic foundations,* the latter being the first of its kind in Germany. The late *Otto Offergeld* from 1873 acted as manager to the company. Since then Messrs. *L. Seifert* and *L. Backhaus* as chief managers have divided between them the extensive German and foreign business of the firm, which from lack of space can only be indicated in outline in the following pages.

With regard to the bridges built by the Harkort Company within the German frontiers, the tables repeatedly referred to furnish some information. They contain 10 bridges over the Rhine, 2 over the Moselle, 4 over the Weser, 5 over the Elbe and 3 over the Vistula, all built by the firm. In addition the following structures belonging to other branches of engineering, deserve to be noticed: *The Lighthouse on the Rothersand*, a highly important work designed by *Seifert,* particulars of which will be found in the Appendix; further the whole of the *lock gates* and *swingbridges* required for the North Sea—Baltic Canal; finally three bridges over the Elbe-Trave Canal at Lübeck, one of which, viz. the Mühlenthor Bridge, is shown in fig. 34.

The activity of the Harkort Company to-day extends to all parts of the world, and its special system of *pin-bridges* (as described in paragraph 21) has materially contributed to its present flourishing condition. The following are amongst prominent bridges sent abroad by the Company:

Norway: Over the Minnesund at Minne (see fig. 158); over the Glomnen at Langnaes; the viaducts over Solbergdalen and Haaböl-Elf;

Sweden: Over the Göta-Elf at Trollhättan, over the Motalaström and the Velanda Viaduct;

Finland: Over the Uleå-Elf at Uleåborg, over the Wuoksen at Jäskis and the Aura-Å at Åbo;

Russia: Over the Msta at Werebja;

Egypt: Over the Freshwater-Canal near Mehalet el Kepir;

Roumania: Over the Argesch near Pitest and Copaceni, over the Jalomitza near Targu-Veste and Pucioasa, over the Oltez near Bals:

Servia: Over the Morawa at Tschuprija;

Spain: Over the Jarama at Arganda, over the Nervion at Bilbao, over the Udondo, Luchana, Durango, etc.;

Portugal: Over the Ave at Villa do Conde (Oporto), over the Leça, etc.;

China: The stockade of the Canton River near Whampoa and a number of railway bridges;

Java: Over the Bekassierivier, the Tjitandoci, the Pegirian near Batavia, numerous roadbridges as well as railway bridges for the Java State Railways, the Oosterspoorweg Maatschappy, etc.;

Madoera: The whole of the bridges since built for the Madoera-Stoom-Tram Maatschappy;

South African Republic (Transvaal): Roadbridges for the government, for instance over the Wilg-, Pinaars- and Krokodil-Rivier, the Vaalrivier at Standerton (see fig. 182, Appendix), the Olifants-Rivier at Middelburg, and railway bridges for the Nederlandsch-Zuid-Afrikaansche-Spoorweg-Maatschappy, like that over the Kaprivier on the Delagoabay and Komatiport line;

Oranje-Vrystaat (Orange Free State): Roadbridges over the Caledon River near Weepener (Jammersbergsdrift), over the Valschrivier, Riet-, Modder-, Wilg-, Molen- and Korneliusrivier and bridges for the city of Bloemfontein;

Argentine Republic: Railway bridges for the port of Ensenada (La Plata) and the Ensenada Railway, the Ferrocarril del Oeste, etc.;

Nicaragua: A number of railway- and roadbridges, for instance a bridge over the Chiquito and the Quesalquaque Viaduct;

Guatemala: Railway bridges over the Rio Samala and for the Ocós Railway.

In addition numerous *pin bridges* on the Harkort system have been exported to *Japan, Formosa, Siam, Sumatra, Brazil* and *Ecuador.*

In case of some of these foreign bridges *iron piers, consisting of hollow or solid screw-piles* of a special design, perfected by the Company, were made use of. The work of the department for *pneumatic foundations,* already referred to, deserves particular notice. The following foundations were built by it:

1876. 3 Rhine Bridges at Alt-Breisach, Hüningen and Neuenburg.
1877. Lock near Neu-Breisach (Rhine-Rhône-Canal).
1878. Stör Bridge at Itzehoe.
1878. Msta Bridge near Werebia, Russia, Petersburg and Moscow line.
1879. The Griesheim reservoir for the Darmstadt Waterworks.
1880—81. Schlei Bridge near Stubbe.
1881. Ruhr Bridge near Witten—Bommern.
1882. Weser Bridge at Bodenwerder.
1882—85. Lighthouse on the Rothersand in the North Sea (see figures 180 and 180a, Appendix).
1883. Bridge over the Jarama near Arganda in Spain.
1885. Argesch Bridge near Pitest in Roumania, Bucarest and Pitest railway.
1885. Warnow Bridge near Rostock (see fig. 40).
1885—86. Eider Bridge near Friedrichstadt in Schleswig, Heide and Ribe line of the Holsteinische Marschbahn.

1887—89. Reservoir and pump-cistern for the Düsseldorf Waterworks.

1894. Elbe Bridge at Dresden (forming part of the rebuilding of the local railway system).

1895. Saar Aqueduct near Oberhammer, Alsace.

1898—1900. Rhine Bridge at Worms, Worms and Rosengarten railway (see fig. 110).

At the Universal Exhibitions of Vienna, Sydney and Melbourne, as well as the Industrial Exhibitions of Düsseldorf (in 1880) and Amsterdam (in 1883) the Company was awarded first prizes and medals. Attention has already been drawn to the bridge designs of the firm, which have received prizes at the recent competitions and are represented in figures 71, 107, 108 and 110.

The works of the Harkort Company, including bridge department, wagon factory and rolling mills, bordering immediately on the Rhine, are very favourably situated for direct shipment to European and over-sea ports, as well as for railway traffic in all directions. Within the works the raw material and the finished product is carried about on ordinary-gauge lines, about 5 kilometres (3,1 miles) long, the cars being propelled, loaded and discharged chiefly by means of two travelling steam cranes of 16 and 30 H. P. respectively, doing service as locomotives at the same time. For lifting very heavy parts seven large moveable sheers and derricks of a power up to 15 tons, further three travelling cranes worked by hand and 15 fixed derricks are provided. A system of narrow gauge (650 millimetres = 2′ $1^1/_2$″) tramways connects all parts of the yards.

The material brought into the works first enters the main building (see fig. 159), where it is straightened, marked with the centre-punch and, after drilling the rivetholes, joined together on the frames. The large hall of the main building, consisting of three spans, 160 metres (525 feet) long and 38 metres (125 feet) wide, is used for preparing the templates for the maingirders of large bridges, while smaller templates are made in the minor halls, containing the machine-tools. Six large radial drilling machines, by means of which the holes of entire flanges or other finished members of the bridge can be drilled in one operation, are provided in the central nave, though as a rule the holes in each part are drilled separately, and rimered, after joining the parts together. The straightening plant, the small forge, the tilt-mill, the pickling room and different kinds of auxiliary engines are to be found in the annexes to the main hall.

After the rivetholes have been drilled in the main hall, the pieces are carried into the pickling shed. After this

Fig. 158. Harkort Co. Railway Bridge over the Minnesund in Norway. 1880. 15 spans of 20 to 62 metres (66 to 203 feet) with 12 iron piers.

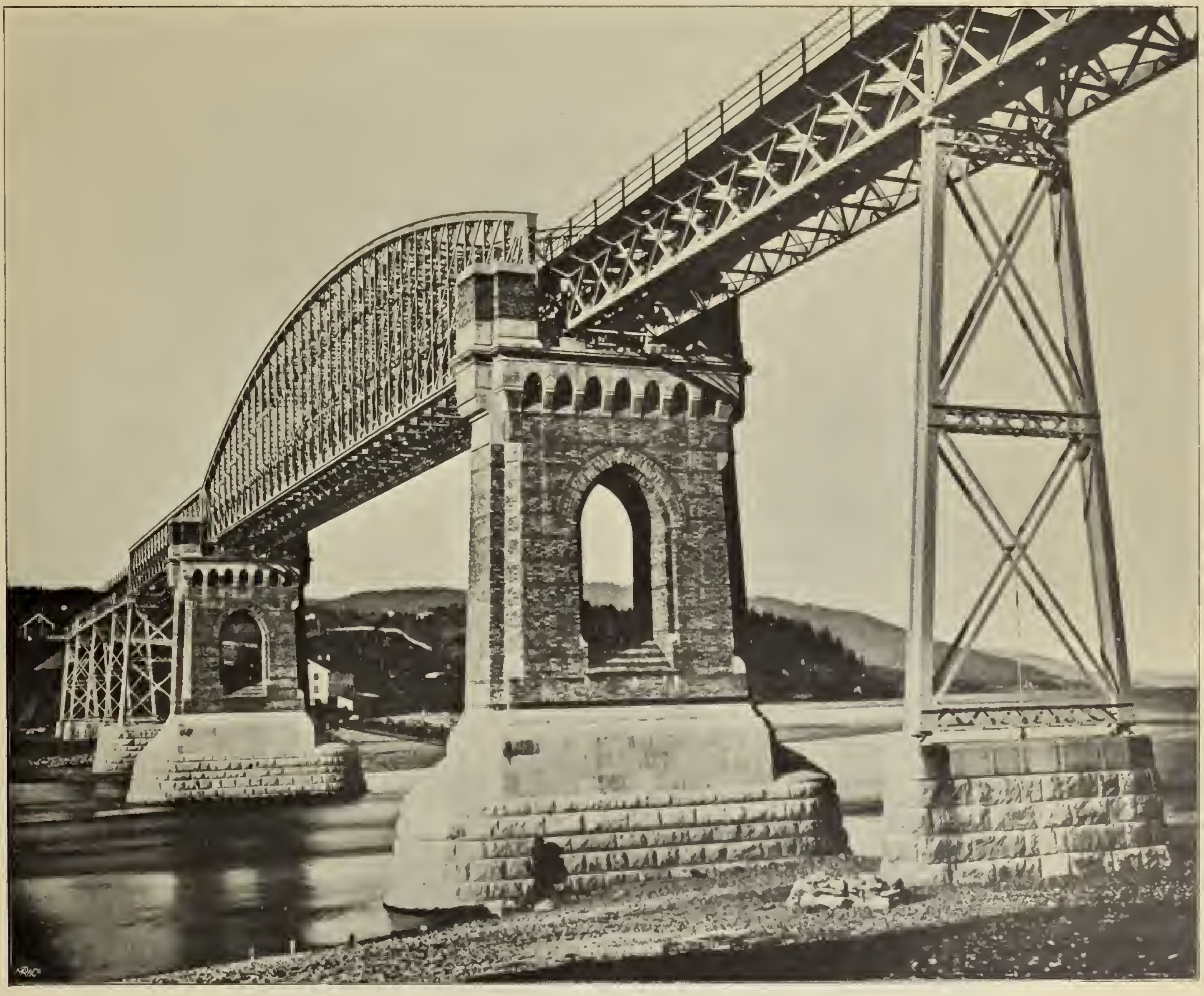
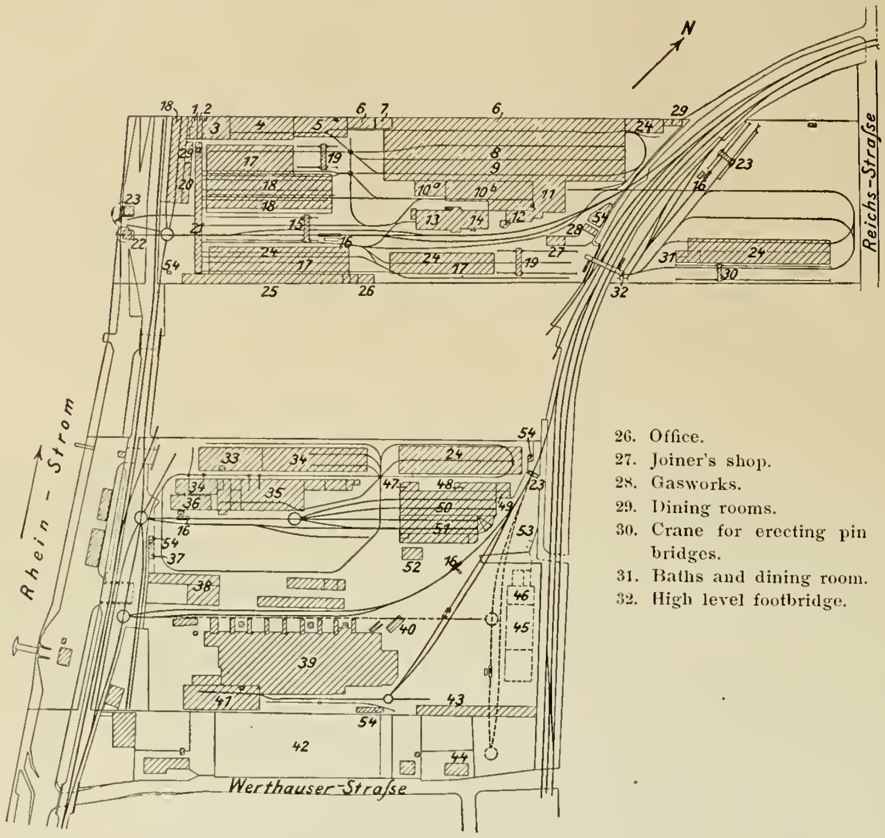


Fig. 159. Plan of the Harkort Company's Bridge Works at Duisburg. Scale 1:5000.

A. Bridge Works.

1. Steam engine and dynamo.
2. Boilers.
3. Rivetting shop.
4. Mechanical workshop.
5. Pickling shed.
6. Tracing shed.
7. Testing machine.
8. Erecting shop.
9. Drilling and mechanical workshop.
10a. Small forge.
10b. Hammer forge.
11. Room for straightening bars.
12. Steam engine and boilers.
13. Tool room.
14. Offices and drawing office.
15. Crane.
16. Balance.
17. Pneumatic Press for rivetting and rimering.
18. Closed work-room.
19. Erecting-crane.
20. Rivet store.
20a. Office.
21. Sliding platform.
22. Travelling crane.
23. Fixed crane.
24. Open work-room.
25. Room for implements used at erection.



26. Office.
27. Joiner's shop.
28. Gasworks.
29. Dining rooms.
30. Crane for erecting pin bridges.
31. Baths and dining room.
32. High level footbridge.

B. Wagon Factory and Rolling Mill.

33. Joiner's shop.
34. Mechanical workshop.
35. Press.
    a) Dynamo.
    b) Boiler and forge.
    c) Steam engine.
36. Store-room.
37. Dining room.
38. Timber shed.
39. Rolling mill.
40. Office.
41. Roll-lathes.
42. Carpenter's yard for making scaffolding.
43. Store of rollers.
44. Officers' houses.
45. Projected central station for boilers and engines.
46. Baths.
47. Repairing-shop.
48. Wagon fitting-shop.
49. Steam-heating plant.
50. Wagon-building shop.
51. Varnishing room.
52. Coke-washing shed.
53. Plant for pneumatic foundations.
54. Doorkeeper.

they are taken in hand by the engineers and rivetters. The rimering of the holes is partly done at present by hand, chiefly however by means of tools worked by compressed air. The rivetting, too, if possible, is done by compressed air-rivetting machines, carried about by light travelling cranes. Just at present the works are about to introduce rimering tools worked by electricity.

Bridge bearings as well as the mechanical parts of swing-bridges are made in the adjoining mechanical workshops. The painting of the finished parts (with the exception of the oiling) is always done in that part of the yards, where the rivetting takes place. The Harkort Company makes its own rivets. Among the remaining plant of the works the following may be mentioned: A Grafenstaden testing machine, an apparatus for testing complete girders and a very large stock of building implements of all kinds.

Fig. 160. Harkort Co. Derrick in Messrs. Blohm & Voss' yard at Hamburg.

In addition to iron bridges the Harkort Company have made numerous iron structures for large buildings and for the purposes of harbour- and canal construction as well as mining. Among these the following may be mentioned: The *spire of St. Peter's Church* at Hamburg, *warehouses* and *repositories* for Hamburg, Magdeburg and Cologne, *silos* for Stettin, Lüneburg and Boulogne, *shaft- and hauling frames, turntables, sliding platforms* and *cranes*. An example of the latter is shown in fig. 160, representing a derrick in Messrs. Blohm & Voss' yards at Hamburg.

The *total output* of the firm, as specified in the following table, is equal to an average production of 12 170 tons a year.

Table VII.

Total output of bridge- and ironwork by the Harkort Company's Bridge Department from 1889 to 1898.

Name of Country	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	Total in 10 years
	t	t	t	t	t	t	t	t	t	t	t
A. Europe.											
Germany	6 242	11 787	7 571	10 141	11 310	12 083	8 339	9 187	9 552	10 057	96 269
Holland	—	—	—	—	—	—	—	—	—	1 034	1 034
Denmark	—	—	—	—	—	—	—	—	8	75	83
Finland	93	—	876	365	62	22	399	338	222	162	2 539
Greece	248	—	5	—	—	—	—	4	—	—	257
Bulgaria	—	—	—	—	—	—	—	354	—	—	354
Roumania	—	—	1 606	148	19	—	—	—	188	250	2 211
Italy	—	20	—	—	—	—	—	—	—	—	20
Spain	—	29	—	22	—	—	2	—	—	—	53
B. Asia.											
China	1 455	75	180	223	132	—	—	—	97	—	2 162
Japan	1 109	1 354	123	100	43	1 807	269	756	715	19	6 295
Sumatra	113	12	207	37	42	—	1	149	—	22	583
Java	—	165	175	272	1 072	83	189	555	—	1 795	4 306
Siam	—	—	—	—	—	—	—	—	—	288	288
C. Africa.											
Transvaal	—	360	600	95	33	5	—	84	97	—	1 274
Orange Free State	—	—	30	875	128	—	—	—	60	—	1 093
Cape Colony	—	—	503	—	—	—	—	—	—	—	503
Egypt	—	—	—	—	—	—	—	774	—	—	774
D. America.											
Brazil	439	199	124	33	110	—	—	195	—	—	1 100
Argentine Republic	—	—	—	189	—	—	—	—	—	—	189
Mexico	—	—	—	—	50	—	—	5	—	—	55
Guatemala	—	—	—	—	—	—	—	—	261	—	261
Total	9 699	14 001	12 000	12 500	13 001	14 000	9 199	12 401	11 200	13 702	121 703

27. PHILIPP HOLZMANN & CO., LD., FRANKFORT-ON-MAIN. The firm of builders, from which this company took its origin, dates back to 1856. At that time the father of the present Mr. *Philipp Holzmann,* Königlicher Baurath, having up to that date been busy chiefly with railway work, settled at Frankfort-on-Main to build there works for the manufacture of building material in addition to a steam saw-mill, taking his sons Philipp and Wilhelm into the business towards the end of the fifties. Early in 1865 the two latter took over the concern and worked it as a trading company under the firm of "Philipp Holzmann" for their own account.

At the beginning of the seventies the growing business necessitated the raising of some further working capital, and early in 1872 the *International Building Society* of Frankfort-on-Main accordingly entered the firm in place of Mr. Wilhelm Holzmann with a large amount of capital. The chief management of the new *"Commanditgesellschaft Philipp Holzmann & Cie."* was taken over by Mr. Philipp Holzmann himself.

After sufficient means had thus been obtained for taking building contracts to any extent, the abilities and commercial experience of Mr. Philipp Holzmann, who commands an extensive knowledge of the technical as well as the business part of the building trade, became the means of rapidly raising the firm to the front rank of German builders.

In order to make sure, during the lifetime of the present manager, of the permanence of the present extensive business operations, on January 1, 1895, the direction of the firm was taken over by a board of management, consisting of members of the firm of proved ability, assisted by a board of directors. At the same time the business was changed into a limited company of the same name and provided by the owners, including the managers, with a capital of 6 million Marks (£ 300 000).

At present the board of directors consists of the following gentlemen:

Mr. Philipp Holzmann, Baurath, chairman,
Mr. Marcus M. Goldschmidt, Kommercienrath,
Mr. A. von Kauffmann, Architect,
Mr. Jacob Lion, bank manager,
Dr. Kilian von Steiner, Geh. Kommercienrath,

while the following gentlemen form the board of management:

Mr. Hermann Ritter, architect, chairman,
Mr. Wilhelm Lauter C. E.
Mr. Karl Sonntag C. E.
Mr. Adolf Haag C. E.
Dr. jur. Felix Reinert.

The company takes contracts for

Large buildings,
Railways, roads and *hydraulic work,*
Bridges, canals and *waterworks,*
the supply of *stone masonry* and *bricks,*

furnishing designs at the same time.

The *central management* of the firm is at Frankfort-on-Main, while at present there are branches at Berlin, Munich, Hamburg, Strassburg, Karlsruhe, Mannheim, Cologne, Düsseldorf, Duisburg and Nuremberg.

The company owns

a) *Brickworks*

at Hainstadt a. M. and Gehespitz near Frankfort for facing-bricks; at Sauen near Fürstenwalde-on-Spree for facing- and ordinary bricks; at Rosenkranz on the North Sea-

Baltic Canal and at Rödelheim near Frankfort for ordinary bricks. — The total output of the brickworks amounts to 60—70 million bricks a year and the area supplied extends over the whole of Germany, Switzerland, Belgium and Holland.

b) *Stonemason's yards and quarries*

in the Main Valley for red stone,

at Lauterecken in the Palatinate, - Bayerfeld, - Olsbrücken — for greyish-green stone,

- Altleinigen — for yellow stone,

- Burgpreppach in Lower Franconia, - Cudowa in Silesia — for white stone,

- Hockenau in Silesia, - Deutmannsdorf, - Kesselsdorf near Rockwitz — for yellow-white stone,

- Brohl-on-Rhine for tuff.

c) *A Manufactory of building materials*, including joiner's and locksmith's shop, and forge.

d) *Sawmills* for timber and stone at Frankfort-on-Main.

e) *Sculptor's studios* at Frankfort-on-Main.

The following may be mentioned among the more important *buildings* constructed by the company:

Friedrichshof Castle at Cronberg, belonging to Her Majesty the Empress and Queen Frederick,
Central Railway Station at Frankfort-on-Main,
Opera - - - -
New Post Offices - - - -
Palmengarten - - - -
Imperial Palace at Strassburg in Alsace,
Emperor William-University at Strassburg in Alsace,
Townhall at Hamburg,
Warehouses at Hamburg,
the Niederwald Monument,
the Emperor William-Monument at Koblenz,
Barracks at Dieuze, Metz and Mayence,
Fortifications at Metz,
Powder Mill at Hanau,
Municipal Electric Stations at Frankfort-on-Main, Mayence and Mannheim,
Exhibition Buildings at Chicago, Nuremberg, Leipzig, Berlin and Paris,
Central Railway Station at Amsterdam,
Warehouse at Derindjé in Asia Minor,

not to mention numerous private and public buildings, churches, villas, office- and bank buildings, factories, etc., at Frankfort-on-Main, Berlin, Munich, Cologne, Strassburg, Metz, Basle, etc.

Stone masonry work has been supplied on a large scale for the following buildings in addition to those already mentioned:

Imperial Parliament Buildings, Cathedral and Church of Grace at Berlin,
Royal Law Courts at Munich.

Bridges:

Roadbridge over the Rhine at Mayence (see page 41),
Two Roadbridges over the Rhine at Basle,
Bridge over the Rhine at Düsseldorf,
Bridge over the Rhine at Strassburg,
Carola Bridge over the Elbe at Dresden,
Two Bridges over the Oder at Frankfort-on-Oder and Stettin,
Emperor William- and Moltke Bridges at Berlin,
Moselle Bridge at Longeville near Metz,
Six Bridges over the Main at Frankfort, Offenbach and Kostheim,
Quay Bridge at Zürich,
Goldeborgsund Bridge in Denmark,
Two Bridges over the Weser and a bridge over the Fulda.

Hydraulic Work:

North Sea-Baltic Canal, lots IX, XIII and XIV,
Vistula Cutting at Danzig,
Oder-Spree Canal,
Canalization of the Main between Mayence and Frankfort,
Canalization of the Fulda,
Elbe-Trave Canal,
Quays at Zürich,
Harbour Works at Kuxhaven, Hamburg, Mannheim, Duisburg, Torgau, Orth, Fehmarn, Cologne and Bamberg,
Enlargements of locks on the Rhine-Rhône Canal,
Docks for the Imperial Navy at Kiel.

Railway Work:

Kraichgau Railway (Durlach—Eppingen),
Strategic Railway (Weizen—Immendingen),
Courcelles—Teterchen in Lorraine,
Wittringen—Kahlhausen in Alsace,
Circular Railway at Karlsruhe,
Landquart—Davos in Switzerland.

Waterworks at:

Frankfort-on-Main, Berlin, Munich and numerous other Bavarian towns, Innsbruck.

Sewage and Drainage Works at:

Frankfort-on-Main, Munich, Stuttgart, Hanau, Mannheim, Karlsruhe, Baden-Baden, Homburg, Krefeld, Düsseldorf, Offenbach, Regensburg, Linz, etc.

The following figures give some idea of the extent and importance of the business done by the company: During the last years the average annual turnover amounted to 20 million Marks (£ 1 000 000), 7 to 8 millions being paid in wages.

During the summer months 12 to 15 000 workmen are employed by the firm.

28. THE UNITED AUGSBURG AND NUREMBERG ENGINE WORKS, LD. (VEREINIGTE MASCHINENFABRIK AUGSBURG UND MASCHINENBAU-GESELLSCHAFT NÜRNBERG). The establishment of the original Nuremberg Works in 1837 by the Nuremberg merchant *Johann Friedrich Klett* (1778—1847) has been already referred to on page 94). Klett commenced work in his little factory, to which a foundry had been added, with about a dozen workmen. In 1842, when this number had already increased to 50 or 60, he procured the first steam engine, and at his death in 1847 the number of workmen amounted to 120. Towards the middle of the century the firm of Klett & Co., carried on from 1847 by *Theodor Cramer,*

Klett's son-in-law, turned its attention to the manufacture of articles required for railway purposes, particularly *railway cars, turntables, sliding platforms,* etc. In 1852—53 a *Bridge Department* was added.

The construction by the firm of the renowned *Günz Bridge* on the Maximilian Railway has already been described in detail on page 56. This was followed in 1854 by the important glass and iron structure of the *German Industrial Exhibition at Munich.* The erection of this building, being an example of the application of iron to architectural purposes, attracted a good deal of attention at the time, the more so, as it was accomplished (design included) within the short space of 8 months.

During the fifties the firm did some excellent work in bridge building (see preceding chapter and Table I), prominent examples being the *Isar Bridge at Grosshesselohe* and the *Rhine Bridge at Mayence*[61]). At the erection of the Rhine Bridge, which is 1036 metres (3400 feet) long and consists of 32 spans, it proved necessary to establish special workshops near the site at Gustavsburg. When, however, after the completion of the bridge in 1862, orders for railway- and roadbridges began to pour in, it was decided to retain these temporary workshops as a permanent branch of the Nuremberg Works under the designation of the *Gustavsburg Bridge Works.* In this manner the Gustavsburg branch, to which in 1894 large boiler works were attached, came to be established, representing to-day one of the busiest centres of the original house at Nuremberg.

In 1857 *Heinrich Gerber,* a Royal Oberbaurath at Munich, who by the scientific treatment of the problems of iron construction, duly acknowledged in the preceding pages, has materially contributed to their rational solution, was appointed manager of the Bridge Department. The chief management of the firm in 1848 was confided to *Ludwig Werder* (1808—1885), who has made his name known in different branches of engineering. The *Werder testing machine* (see page 50) has become known all over the world, and the same may be said of the *Werder-rifle,* with the aid of which the Bavarian army has won glorious victories. Under Werder's able direction the Nuremberg Works visibly continued to increase in size, until in the course of time they comprised a whole suburb of the city of Nuremberg. The different branches of the business, including *mechanical engineering, foundry, boiler works, iron construction* and *wagon building* were being continually perfected, and new branches of manufacture, like that of *wire-tacks* (in 1850), were gradually added.

In 1873 the firm of Klett & Co. (with the exception of the wire-tack business) was floated as a joint-stock company, consisting of two separate departments, viz. the *Nuremberg Engine Factory, Ld.* (*"Maschinenbau-Actien-Gesellschaft Nürnberg"*) at Nuremberg and the *South German Bridge Works* (*"Süddeutsche Brückenbau-Anstalt"*) at Gustavsburg. Both departments, however, were again united in 1884, and, after Gerber had resigned the management of the Gustavsburg works, the entire business was being directed by *Friedrich Hensolt,* Kommerzienrath, and *Anton Rieppel,* chief engineer. From 1892 Baurath *Rieppel* has acted as sole manager to the company, which since then has been amalgamated with the Augsburg Engine Works, Ld. At present, therefore, the firm owns three different establishments, at Augsburg, Nuremberg and Gustavsburg (near Mayence) respectively, plans of which are shown in figures 161 to 163.

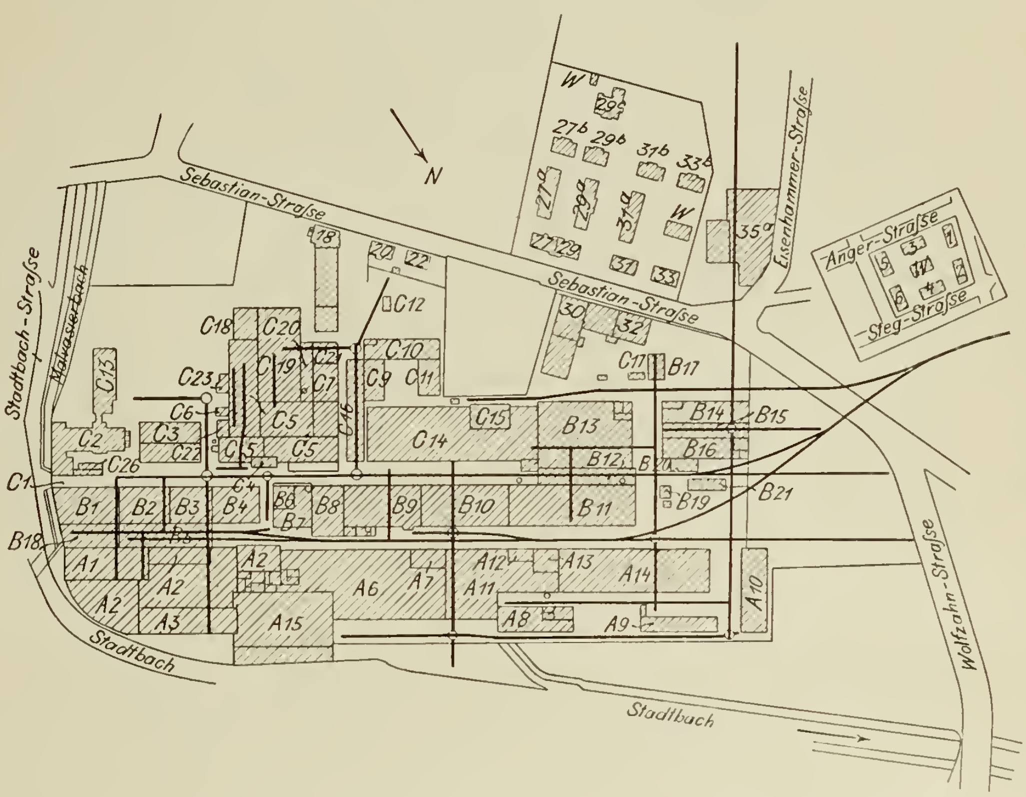
At Augsburg engine building only is carried on, at Nuremberg engine- and wagon building, at Gustavsburg bridge-, boiler- and wagon building. The old Nuremberg works, which no longer came up to modern requirements, had to be pulled down and replaced by the new establishment at Gibitzenhof near Nuremberg, as shown in plan. The piece of ground provided for the purpose extended over 26 hectars (64 acres), being 740 metres (2430 feet)

Fig. 161. The *Augsburg* Works of the "Ver. Maschinenfabrik Augsburg und Maschinenbau-Gesellschaft Nürnberg". Scale 1:5000.

Letter A.
1 and 2. Turning shop.
3. Erecting shop.
6. Printing machine-workshop.
7. Printing machine-store room.
8. Saw mill.
9 and 10. Timber sheds.
11. Printing machine-fitting shop.
12. Engine house.
13. Boiler house.
14. Erecting-shop.
15. Fitting-shop for ice-making and printing machines.

Letter B.
1 to 4. Fitting shops.
5. Covered yard.
6. Boiler house.
7. Engine house.
8 to 13. Foundry.
14 to 17. Sheds.
18. Store room.
19 to 21. Sheds.

Letter C.
1. Watchman's passage.
2. Offices.



3. Joiner's shop.
4. Engine house.
5. Forge and boilerworks.
6. W. C.
7. Boiler house.
9. Sand- and loam-shed.
10. Shed for moulding-boxes and patterns.
11. Foundry shed.
12. Shed.
13. Office.
14. Iron foundry.
15. Metal foundry.
16. Coal shed.
17. Farrier's shop.
18 to 21. Boiler workshops.
22 23. Store rooms for plates.
1 to 6. Workmens' dwellings.
22 to 29 b. „ „
31 to 33 b. „ „
18. Store room and house-keeper.
20. Doorkeeper.
29 c. Officer's house.
35 a. Tube-workshop.
W. Scullery.

Fig. 162. The *Nuremberg* Works at Gibitzenhof of the "Ver. Maschinenfabrik Augsburg und Maschinenbau-Gesellschaft Nürnberg".
Scale 1 : 5000.

Letter A.
1. Store room.
2. Boiler and engine house.
3. Gas-generator.
4. Gas-holder.
5. W. C.
6. Locomotive sheds.
8. Boiler house.
9. Refreshments.
10—12. W. C.
16. Water tower.
18. Cooling-house.
19. Coal and pig iron shed.
20. Baths.
21—22. Doorkeeper.
23. Cart house.
24. Horse stables.
25. Sale of stamps.
26. Kitchen.
27. Gas-meter.

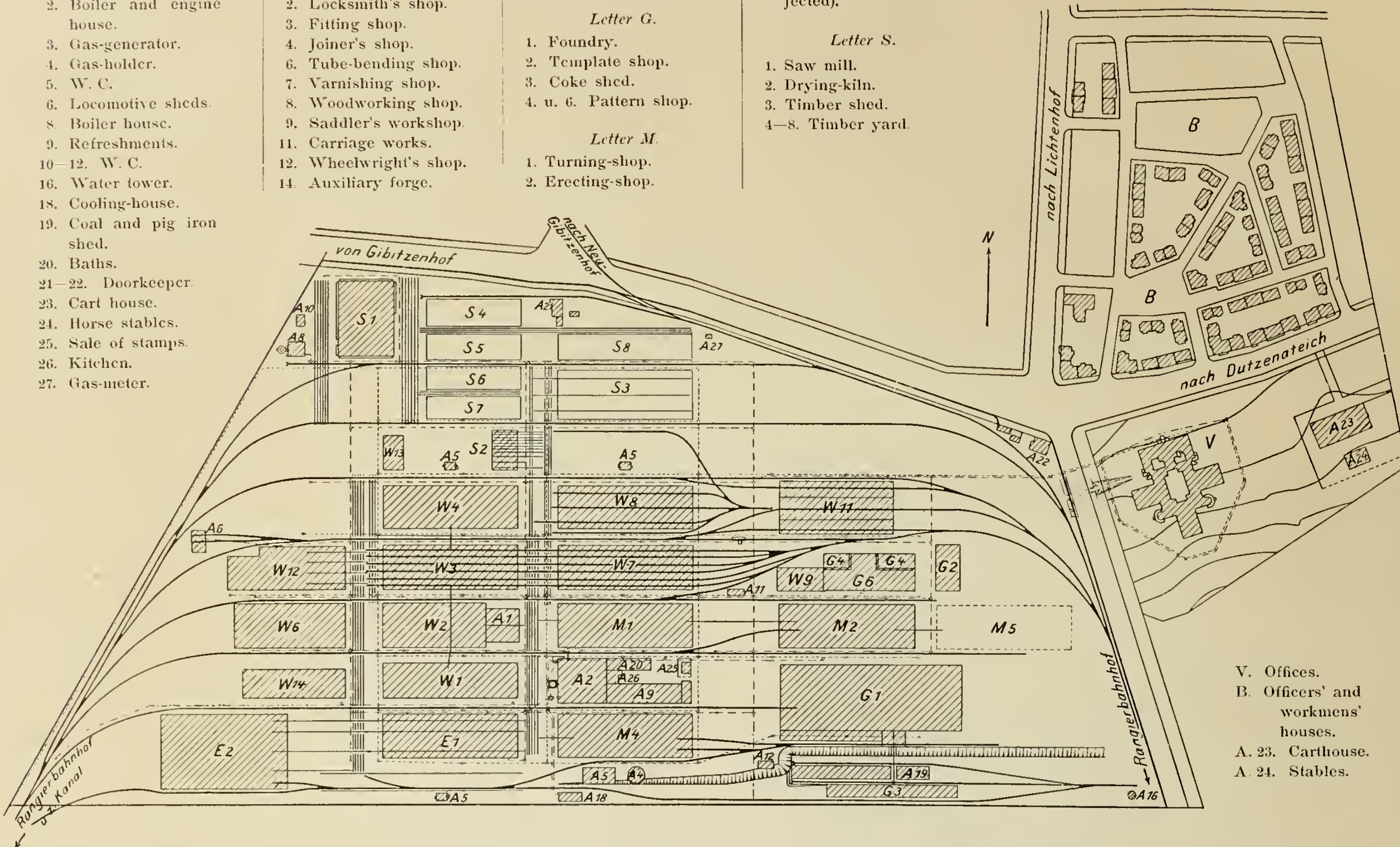
Letter W.
1. Forge.
2. Locksmith's shop.
3. Fitting shop.
4. Joiner's shop.
6. Tube-bending shop.
7. Varnishing shop.
8. Woodworking shop.
9. Saddler's workshop.
11. Carriage works.
12. Wheelwright's shop.
14. Auxiliary forge.

Letter E.
1 and 2. Girder workshop.

Letter G.
1. Foundry.
2. Template shop.
3. Coke shed.
4. u. 6. Pattern shop.

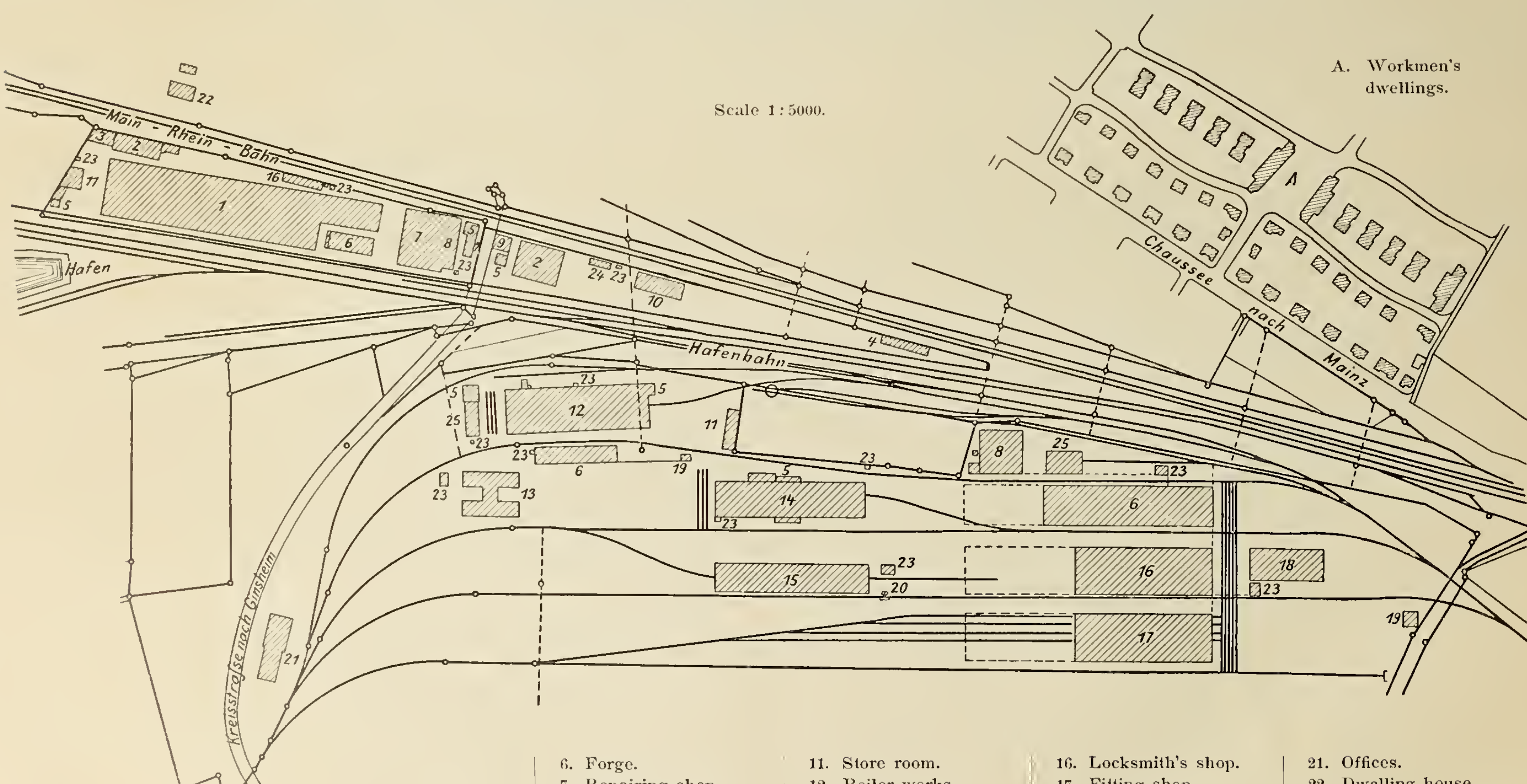
Letter M.
1. Turning-shop.
2. Erecting-shop.
4. Gas engine factory.
5. Erecting-shop (projected).

Letter S.
1. Saw mill.
2. Drying-kiln.
3. Timber shed.
4—8. Timber yard.



V. Offices.
B. Officers' and workmens' houses.
A. 23. Carthouse.
A. 24. Stables.

Fig. 163. The *Gustavsburg* Works of the "Ver. Maschinenfabrik Augsburg und Maschinenbau-Gesellschaft Nürnberg".



1. Erecting-hall.
2. Shed for straightening bars.
3. Drilling shed.
4. Timber store.
5. Office and dining room.
6. Forge.
7. Repairing shop.
8. Engine house.
9. Refreshment room.
10. Shed for shaping-machines.
11. Store room.
12. Boiler works.
13. Dining rooms.
14. Erecting-shop for girders.
15. Hall.
16. Locksmith's shop.
17. Fitting shop.
18. Wagon shed.
19. Doorkeeper.
20. Weighing-machine.
21. Offices.
22. Dwelling house.
23. W. C.
24. School.
25. Welding shed.

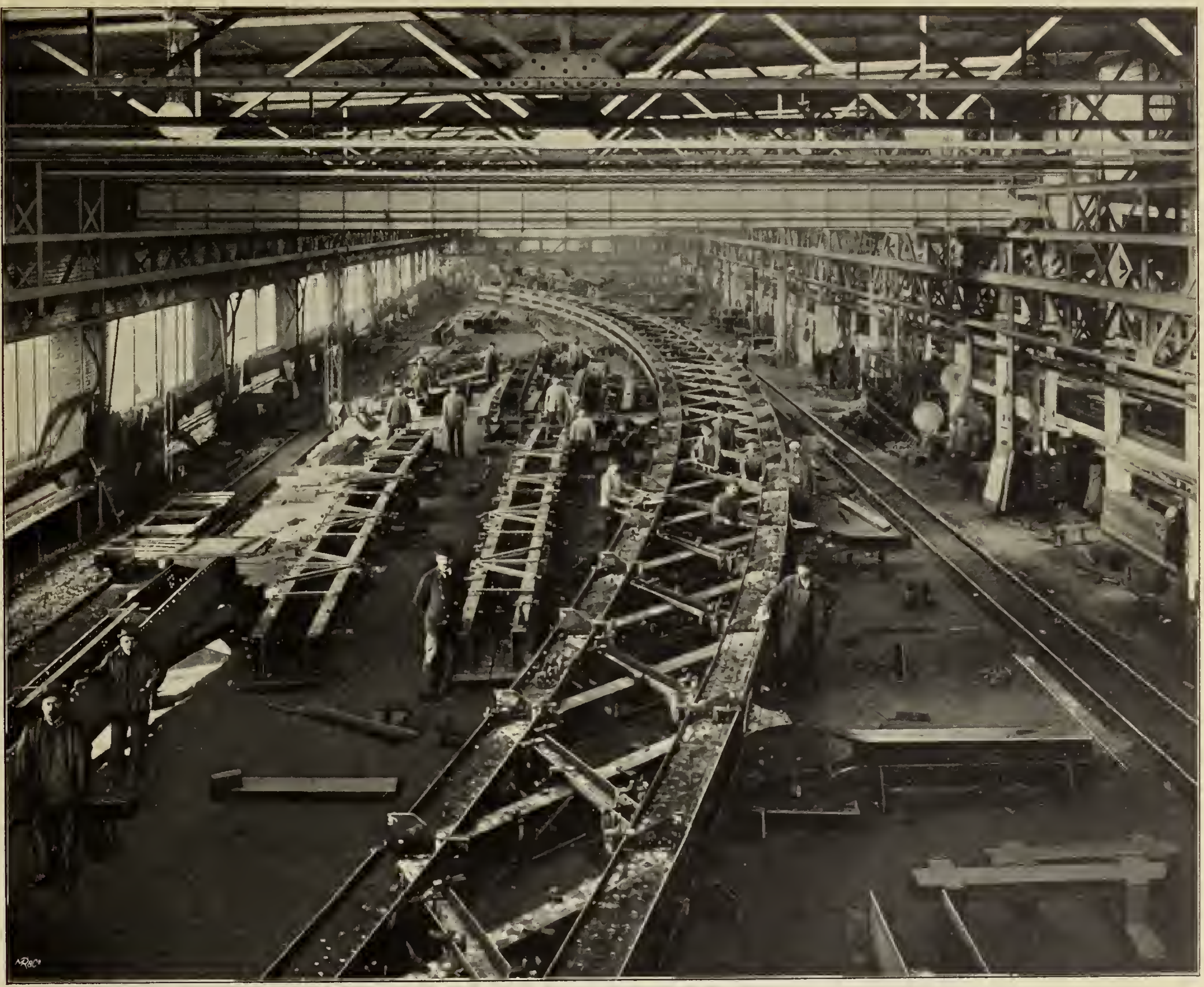
long by 350 metres (1150 feet) wide. Parallel lines of railway were put down over its entire length and connected to the South Western loop line for the purpose of taking in the raw material, as well as to the South Eastern line for despatching the finished product. The different workshops, being each about 35 metres (115 feet) wide, have on purpose not been made much longer than about 100 metres (327 feet), the parallel line of rail mentioned above being therefore about 40 to 50 metres (131 to 164 feet) apart. Between the rows of workshops there are roads at least 25 metres (82 feet) wide, provided with two sliding platforms worked by machinery.

The Gustavsburg and Nuremberg Works supply *iron bridges, halls, roofs, factories, warehouses, lighthouses, blast furnace frames, iron masts for electric lighting* and similar structures, the bridges and other iron buildings of larger size being made at Gustavsburg. The *Central Railway Stations* of *Zürich, Munich, Mayence, La Plata and Dresden* are excellent examples of their class, though the main activity of the works is naturally directed to bridge building.

The principal drawing offices of the bridge department are at Nuremberg, working drawings only being made at Gustavsburg. The company has made arrangements enabling it to contract for bridge pier work as well, including *pneumatic foundations*. Since 1886 *bridges with piers and abutments made entirely of galvanized iron* have been built by it according to the approved system of its chief manager. Among the numerous bridges of this kind the railway bridge, 250 metres (820 feet) long, over the Temes in Hungary, the piers of which do not contain a single stone, deserves particular attention; the iron piles in this case were driven in as much as 12 metres (39 feet).

Up to the present the Gustavsburg Works have built about 1500 railway bridges, including many of large dimensions. Prominent examples are contained in Tables I to VI, as for instance *the Rhine Bridge at Mayence, the High Level Bridge at Grünenthal over the North Sea-Baltic Canal* and the far-famed *Emperor William Bridge over the Wupper Valley near Müngsten*, which was erected by the Gustavsburg Works in 1893—97 according to Rieppel's designs, and a model of which will be on view at Paris (compare Appendix).

Fig. 161. Arch of the Worms Bridge over the Rhine at the Gustavsburg Works.



The value of the total annual output of the firm amounts to about 10 to 13 million Marks (£ 500000 to £ 650000). The following figures represent the production of bridge- and ironwork by the Gustavsburg and Nuremberg Works:

Year:	1894/95	1895/96	1896/97	1897/98	1898/99
Tons:	10232	11429	13607	13020	17015.

For the benefit of these two works a workmen's pension-, widow's and orphan's fund has been raised, the members of which, *without contributing to it*, after 5 years' employ by the company have the right to claim a pension in case of permanent disablement. In addition a pension society has been formed, granting pensions to the officers as well as to their widows and orphans. Among other charitable institutions the following may be mentioned: For *educational purposes*, besides a fund for providing workmen of proved ability with gratuitous instruction, a factory school at Nuremberg with a range of teaching going beyond that of primary schools, as well as a school for apprentices; for *housing workmen's families*, 90 artisan's dwellings at Nuremberg, 123 at Gustavsburg. At the new Gibitzenhof Works near Nuremberg (see fig. 162) a model artisan's quarter will be established; in addition to other institutions of common benefit a hundred houses provided with the latest sanitary improvements, accomodating about 410 families, are to be erected there.

The *Gustavsburg Bridge Works*, including the *Boiler Works* and the *Wagon Factory* (see fig. 163) cover an area of roughly 200 000 square metres (239 000 square yards) and employ about 2000 workmen. They are provided with 7 steam boilers of a total heating surface of 830 square metres (8940 square feet); 4 steam engines of together 800 H. P.; 1 steam- and 1 monkey hammer and about 400 machine-tools.

The abundant equipment of the Gustavsburg Works with efficient, light iron-scaffolding for the erection of bridges of great height deserves particular attention.

Fig. 165. Union Works. Railway Bridge over the Waal at Nymwegen. 1879.

Fig. 166. Union Works. Portal of the Railway Bridge over the Waal at Nymwegen. 1879.

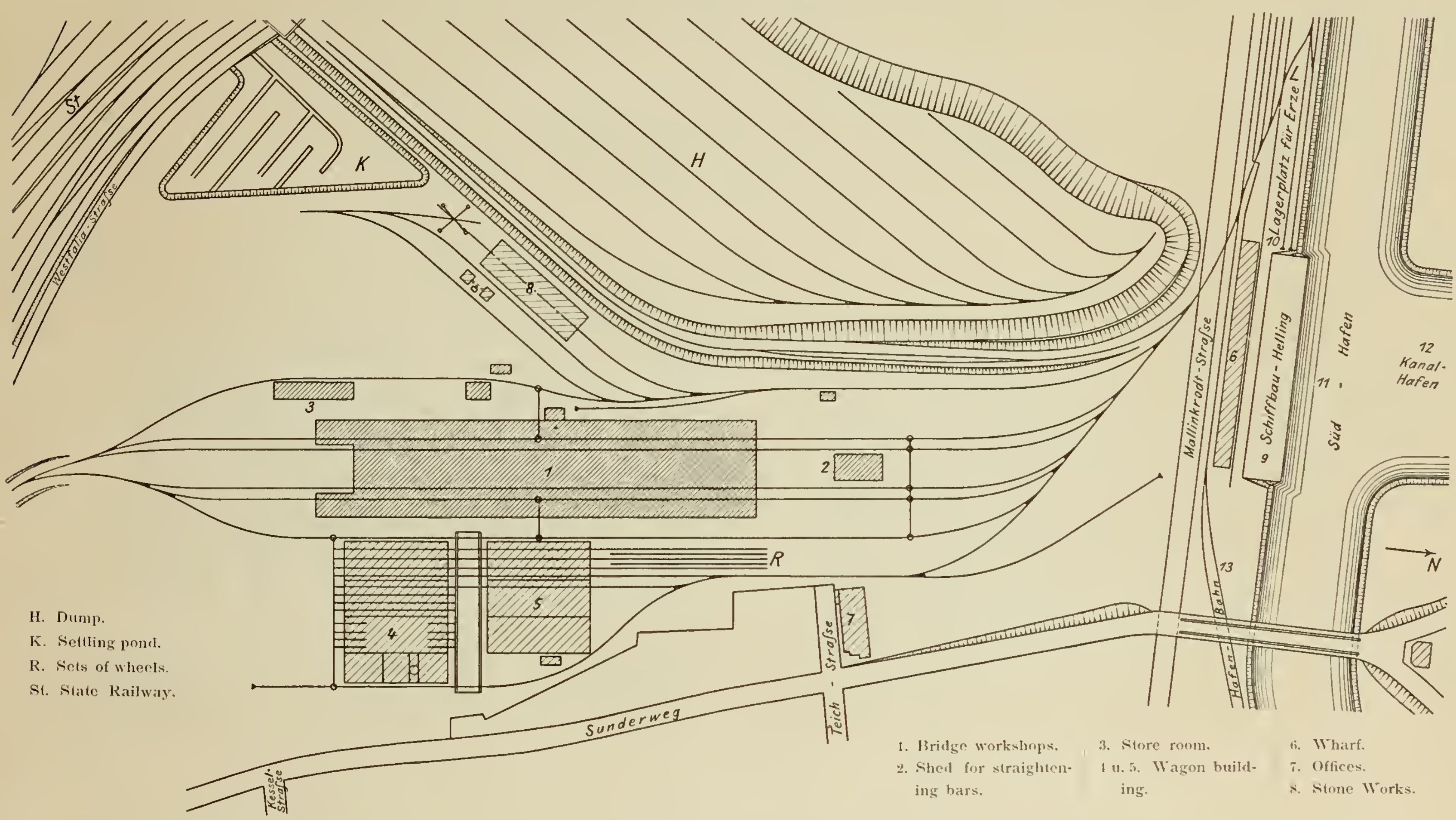
Already the *Inn Bridge at Königswart*[93] (see Nr 21, Table III) was erected in this way, while the hall of the *Zürich Railway Station* (in 1867) was built on travelling frames and that of the *Munich Station* (in 1878) on iron travelling stages[93]). At the Ohe Bridge (see Nr 24, Table III) built in 1877, special iron piers were used to support the iron scaffolding girders. In addition plant for the *pneumatic foundation* of bridge piers and well pits is provided.

The United Nuremberg and Gustavsburg Works draw a distinction between three different groups of structures. The first group consists of wide span bridges, more particularly big arches, the second of bridges of a similar kind, but consisting of several openings of equal span, the third of ironwork for buildings and similar structures of more irregular shape. These three groups are treated in a different manner at the Gustavsburg Works. While the structures forming the third group are made from *templates* in the ordinary way, in case of the second group one of the spans of the bridge is put together complete, its separate parts subsequently serving as templates for the remaining spans. The drilling of the rivetholes through the different bars and plates is done by means of drilling-machines fixed to the columns of the building, the holes through the joints being drilled with a diameter slightly smaller than that prescribed in the drawings. They are subsequently rimered at the shops.

Particular care is bestowed on the manufacture of the structures belonging to the first group. In this case the maingirders are put together in full length, after the geometrical centre lines of all bars have been traced out, and the rivetholes are then marked and drilled through all parts, i. e. webs, angle irons, etc., in one operation. The drilling-machines used for this purpose are suspended from the large overhead travellers and can be moved forward, backward and transversely by electric power, being thus easily shifted to any point desired. The holes in this case are drilled full size at once, any subsequent rimering being therefore dispensed with. By this means the holes are easier made to fit exactly together, and in case of statically undetermined structures all bars can be confidently assumed to be free from initial strain of any kind. This mode of proceeding proved very successful at the erection of the great central arch of the Müngsten Viaduct[94]), as described in the Appendix.

Fig. 164 represents an arch of the Roadbridge over the Rhine at Worms as put together on the frames at the Gustavsburg Works. Figures 186 to 188 (see Appendix) show the superstructure as well as the piers of the *Electric City Railway Barmen-Elberfeld-Vohwinkel*, the details of which have been designed by the Nuremberg Company and will be briefly described in the Appendix.

Fig. 167. Plan of the Union Company's Bridge Works at Dortmund. Scale 1 : 4000.



H. Dump.
K. Settling pond.
R. Sets of wheels.
St. State Railway.

1. Bridge workshops.
2. Shed for straightening bars.
3. Store room.
4 u. 5. Wagon building.
6. Wharf.
7. Offices.
8. Stone Works.

29. THE UNION COMPANY, LD., (GESELLSCHAFT UNION) AT DORTMUND.

The Union Company for Mining, Iron and Steel Industries, Ld., was founded in 1872 by combining a number of separate works, viz. (in chronological order): 1. *The Henrichshütte*, Ld., at Hattingen (of 1854), 2. *The Dortmunder Hütte* (of 1855), 3. The Neuschottland Co., Ld., at Horst near Steele (of 1857) and 4. The mining association *Glückauf Tiefbau* at Barop. These works comprise blast and puddling furnaces, rolling mills, foundries, mechanical workshops, steelworks, a factory of railway appliances and a *bridge department*.

The bridge works are under the direction of Mr. *Schmermund*, chief manager, and Messrs. *Bosse* (for drawing offices) and *Franzius* (for workshops and erection),

chief engineers. The works take contracts for all kinds of iron structures, including *bridges, roofs, station halls, elevated railways, docks, lock gates, weirs, warehouses,* etc., as well as *turntables, hoisting frames* and *plant, ironwork for mining purposes,* etc., with an annual output of about 15 000 tons. Among the larger German bridges of a span

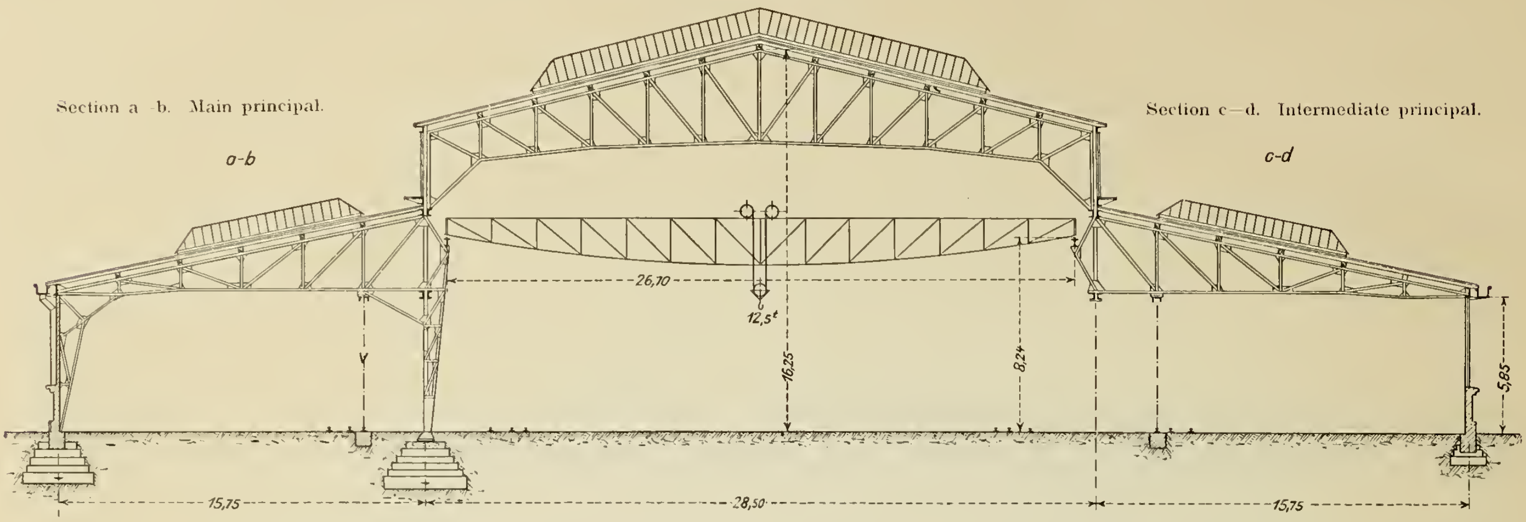
1890—92. Railway Bridges over the Ruhr at Hohensyburg and at Fröndenberg.

1892—93. Roadbridge over the Lesum at Burg and over the Geeste at Bremerhaven.

1895—96. Roadbridge over the Dortmund-Ems Canal at Münster.

Fig. 168—171. New Bridge Workshops of the Union Company ad Dortmund. (Dimensions in metres.)

Fig. 168. Cross section.



V. Electric travelling crane.

Fig. 169. View.

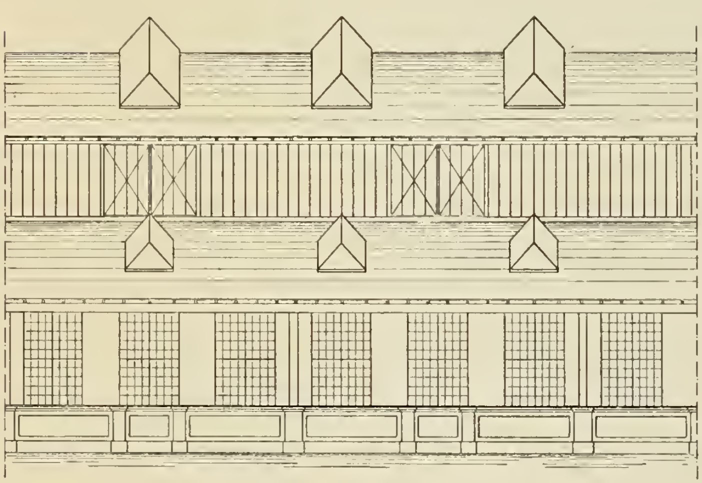


Fig. 170. Longitudinal section e—f.

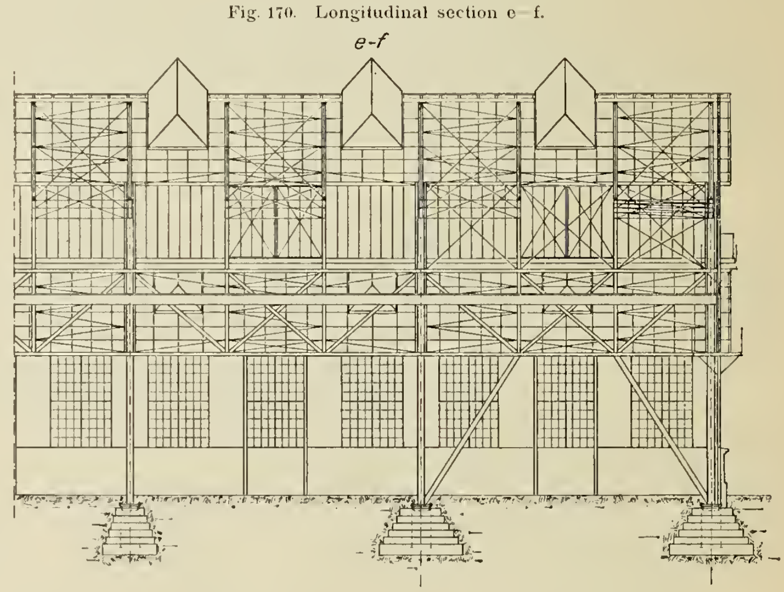
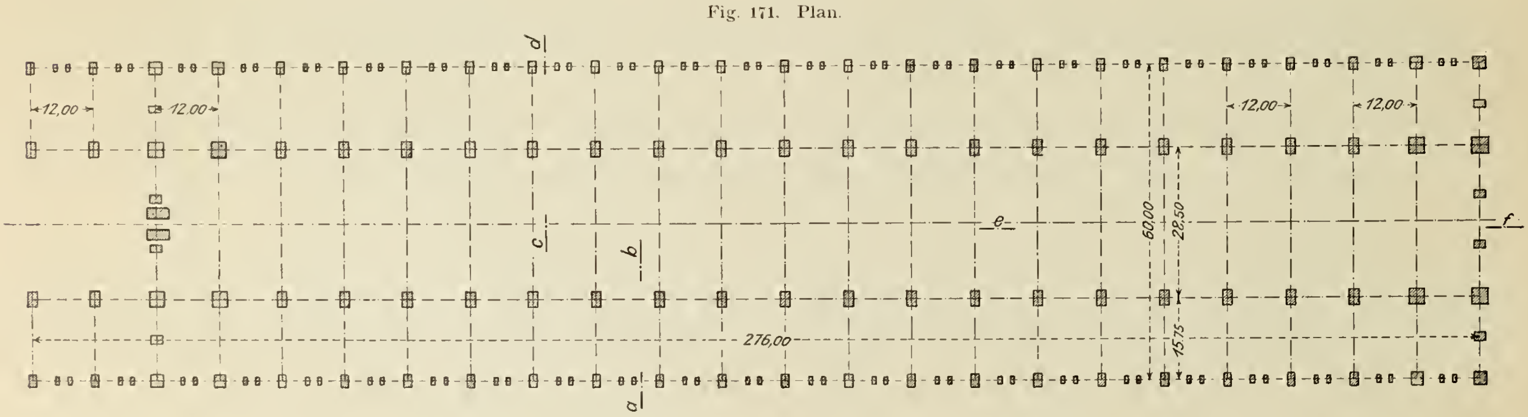


Fig. 171. Plan.



exceeding 30 metres (98 feet), made at the Dortmund Works, the following are the more prominent ones:

1876—79. Railway Bridge over the Vistula near Graudenz (see fig. 89).

1884—85. Roadbridge over the Weser at Holzminden.

1884—85. Railway Bridge over the Elbe at Rosslau.

1885—86. Roadbridge over the Ems at Greven.

1888—89. Roadbridge over the Ihme near Hanover (see page 30).

1896—97. Roadbridge over the Elbe-Trave Canal near Mölln-Schwarzenbeck (see fig. 51 and 192, Appendix).

1897—99. Railway Bridge over the Saale at Grossheringen.

In addition a considerable number of bridges has been sent abroad and erected in all parts of the world by the Union Works, including many *pin bridges of the Company's own system,* among which the following may be mentioned:

1875—76. Railway- and Roadbridge over the Narew at Warsaw. 3 spans of 73 metres (240 feet) each.

1876. Railway Bridges over the Limmat. Swiss North Eastern Railway. Spans of 42 metres (138 feet) and 54 metres (177 feet).

1876—79. Railway Bridge over the Waal River at Nymwegen. 3 spans of 127 metres (417 feet) each and 5 of 53,5 metres (174 feet) each (see fig. 165 and 166).

1880—81. Keysildere Bridge of the Oriental Railway Co. 1 span of 58 metres (190 feet) and 1 of 34 metres (112 feet).

1881—83. Railway Bridges of the Java State Railways.

1883—84. Three Roadbridges over the Glommen near Skarnas. 2 spans of 80 metres (263 feet) each, 1 of 55 metres (180 feet) and 1 of 35 metres (115 feet).

1887—1900. Numerous Railway Bridges for the Samarang-Joana-Stoomtram-Maatschappy, the Kiuschiu Railway Company and for other companies in Java, up to a span of 82 metres (269 feet).

1887—93. Railway Bridges over the Conchas River and the Arroyo Arenales in the Argentine Republic, over the San Pedro, the Quebrada Guanabana and Seca, as well as the La Galera-Viaduct (see fig. 190 and 191, Appendix) in Venezuela.

1890—94. Bridges over the San Francisko, the Rio Grande, the Parahyba, the Rio Jacaré, the Rio Sant-Anna and the Rio Formiga for the Oeste de Minas Railway Company of Brazil.

1893—94. Bridge over the Glommen near Steenviken for the Norwegian State Railways. 2 spans of 60 metres (197 feet) each.

Among the exhibits of the Union Works at Paris (described in the Appendix) particular attention is directed to the new *bridge workshops,* erected in 1898—99 at Dortmund, a plan of which is shown in fig. 167, section, views, etc., being given in figures 168 to 171.

The rectangular new building, which is constructed entirely of mild steel, with the exception of the timber purlins, rafters and roof boarding, has a length of 276 metres (906 feet) and a width (in 3 spans) of 60 metres (197 feet), comprising an area of 16 560 square metres (178 350 square feet) of roofed-in working space, sufficient for 600 to 700 men. In consequence of the unfavourable condition of the subsoil the outer walls are made entirely of iron frame work, while the felt-covered roof of the central span, being 28,5 metres (93′ 6″) wide and 16,25 metres (53′ 4″) high from rail-level, as well as the lean-to roofs of the side spans, each 15,75 metres (51′ 7″) wide, are shown in section in fig. 168. The main principals, supporting all three spans, and resting immediately on the foundation walls, are 12 metres (39′ 4″) apart, while two intermediate principals are carried by longitudinal girders, the purlins, therefore, having a uniform span of 4 metres (13′ 1″).

The building being of unusual length, no complete windbracing over the entire length of the roof has been provided, the windpressure being immediately taken down to the foundation by the principals themselves, while that acting on the intermediate rafters is transmitted to the principals by means of frames (see fig. 170). The windforce acting on the screens is taken by special windgirders adjoining them, provided for the purpose, and transmited to the end panels, where it is taken down to the foundation by frames of suitable design.

The main principals of the central and the side spans, consisting of braced arches with hinges at the springing, are connected to each other in a way to transmit the horizontal thrust of the central span through the side spans down to the foundations. The intermediate rafters of the side spans are supported at the outer wall on columns, while in the plane of the two middle rows of columns they (together with the intermediate principals of the centre span) rest on braced longitudinal girders. The latter are firmly connected to special girders for carrying the electric overhead traveller of the centre nave, which has a span of 26,7 metres (87′ 7″) and a carrying capacity of 12,5 tons (see fig. 168).

Both side spans, too, are provided with moveable cranes worked by electricity (at V, see fig. 168), the upper guide rail being fixed to the bottom flange of the principal. For the purpose of allowing the travelling cranes to move into the open beyond the building, the southern screen is provided with suitable openings, which can be locked.

The building is amply lighted, there being windows in the outer walls as well as above the side roofs (see figures 169 and 170), and all three spans having additional sky-lights, arranged in a transverse direction, with a total lighting area of 6600 square metres (71 080 square feet), compared to a total covered area of 16 560 square metres (178 350 square feet). A sufficient amount of ventilation is obtained by side-lights, moving on rollers, at every third window, in addition to the window-valves of the outer wall.

The iron weight of the building amounts to 1500 tons, being 90 kilos per square metre (165,9 lbs. per square yard) of roofed-in area.

V.

Appendix.

30. THE EXHIBITION OF GERMAN BRIDGE WORKS AT PARIS IN 1900. The exhibition will be found on the first floor of the large building named "Palais du Génie Civil et des Moyens de Transport, Champ de Mars", in the Avenue de Suffren. Plan, longitudinal section and two cross sections of the rooms, as well as the manner of their disposal to the six German firms taking part in the exhibition, are shown in fig. 172. The following paragraphs contain a brief description (arranged in alphabetical order) of the exhibits, pointing out at the same time the exact place, where they are to be found.

I. Maschinenfabrik Esslingen (Esslingen Engine Works) at Esslingen, Württemberg.

Front and sides.

1. *Design of a Cable-Roadbridge at Budapest. Awarded first prize.* Perspective view. — Compare fig. 55.

2. *Cable-Roadbridge over the Argen at Langenargen on the Lake of Constance.* Perspective view. View and plan in 1 : 60. Section in 1 : 20. Details in 1 : 5. — Compare figures 115 to 120 and pages 79 and 80.

3. *A piece of the cable of bridge Nr 2, about 20 inches long, manufactured by Messrs. Felten & Guilleaume of Mülheim-on-Rhine.*

The Cable Bridge over the Argen at Langenargen on the Lake of Constance, designed by the Royal Württemberg Department of Roads and Hydraulic Works, and erected in 1897—98, is made after the model of the Budapest Bridge, being like the latter a stiffened cablebridge. The cast steel cables are supported on the piers by roller bearings, and their ends are anchored down within easily accessible anchor-shafts. The platform as well as the stiffening girders on both sides of the bridge are suspended from these cables by means of adjustable tie-rods. The stiffening girders in connection with the cables form the main carrying structure of the bridge. Though they serve as railings at the same time, their principal object is to stiffen the bridge both in a vertical and a horizontal direction. The cables have a span of 72 metres (230 feet) between the centre lines of the piers and a pitch of 9 metres (29′ 6″). The clear width of the roadway, which has a pavement of wood blocks on concrete, is 6 metres (19′ 8″) between the stiffening girders.

The anchorage blocks as well as the piers, both made of concrete, have been built by the Royal Württemberg Department of Roads. The two steelwire-cables, each 133 metres (436 feet) long, and weighing 20 tons, were made by Messrs. *Felten & Guilleaume* of Mülheim and carried to the site ready made (including the cableheads) on large drums. A piece of cable, about 20 inches long, with the cablehead put on, is exhibited by Messrs. Felten & Guilleaume in group VI.

The weight of the bridge amounts to
about 100 tons of *mild steel* in stiffening girders and platform,
- 15 tons of *cast iron* and *steel* in bearings and anchorages.

4. *Railway Bridge of the Lake of Constance Circular Railway over the Argen.* Perspective view. View and plan in 1 : 60. Section in 1 : 10. Bearing of cross-girders in 1 : 5. — Compare fig. 96.

The *Railway Bridge over the Argen* is situated about 120 metres (390 feet) above the roadbridge just described. Being designed by the Royal Württemberg Board of Railways, it was erected in 1898 with semiparabolic girders of a span of 74,2 metres (243 feet), the platform being below. The main girders like those of the Fordon Bridge (see fig. 32) have a double set of diagonals without verticals and are provided with an intermediate flange. The platform, forming together with the crossgirders a self-contained part of the structure, able to move freely in any direction, is supported on the bottom flanges of the maingirders by hinged bearings, as shown in figures 143 and 144. The connection between diagonals and flange is made rather flexible in order to reduce the secondary strains. With the exception of the portals at the ends of the bridge there is no transverse connection whatever between the main girders.

The weight of the bridge amounts to
about 329 tons of *mild steel* in maingirders and platform,
- 13 tons of *cast iron* and *steel* in bearings.

II. Gutehoffnungshütte (Gutehoffnungs Works) at Sterkrade, Rhine Province.

a) Front.

5. *Roadbridge over the Rhine at Bonn.* 3 water colour- and 5 other drawings. — Compare figures 69 and 105.

Owners: The City of Bonn[92].

Designers: The Gutehoffnungs Works at Oberhausen. R. Schneider, builder, Berlin. Bruno Möhring, architect, Berlin.

Builders: R. Schneider, Berlin, for pier work. The Gutehoffnungs Works for the iron superstructure.

Date of erection: 1896 to 1898.

Description:			*weight*
1 centre span of	187,2 metres	(614 feet),	1800 tons
2 side spans of	93,6 -	(307 feet), each,	1275 -
1 side span of	32,5 -	(107 feet),	115 -

The platform is 14,0 metres (45′ 11″) wide, viz. roadway 7,15 metres (23′ 6″) and the two footpaths 3,425 metres (11′ 2½″) each.

Centre span: Elastic arch with hinges at the springing.

Side spans: Elastic arches with hinges at the springing and braced spandrels.

The design of the Rhine Bridge at Bonn originated in the competition arranged by the city of Bonn in 1894, when, handed in by the Gutehoffnungs Works in connection with R. Schneider, a firm of builders, and R. Möhring, an architect, of Berlin, it was awarded first prize. This design was based on the assumption that the bridge would start from the southern end of the old city, called the "Alter Zoll". The city authorities, however, deciding in favour of a bridge taking the direction on the Vierecksplatz, it became necessary to alter the design accordingly.

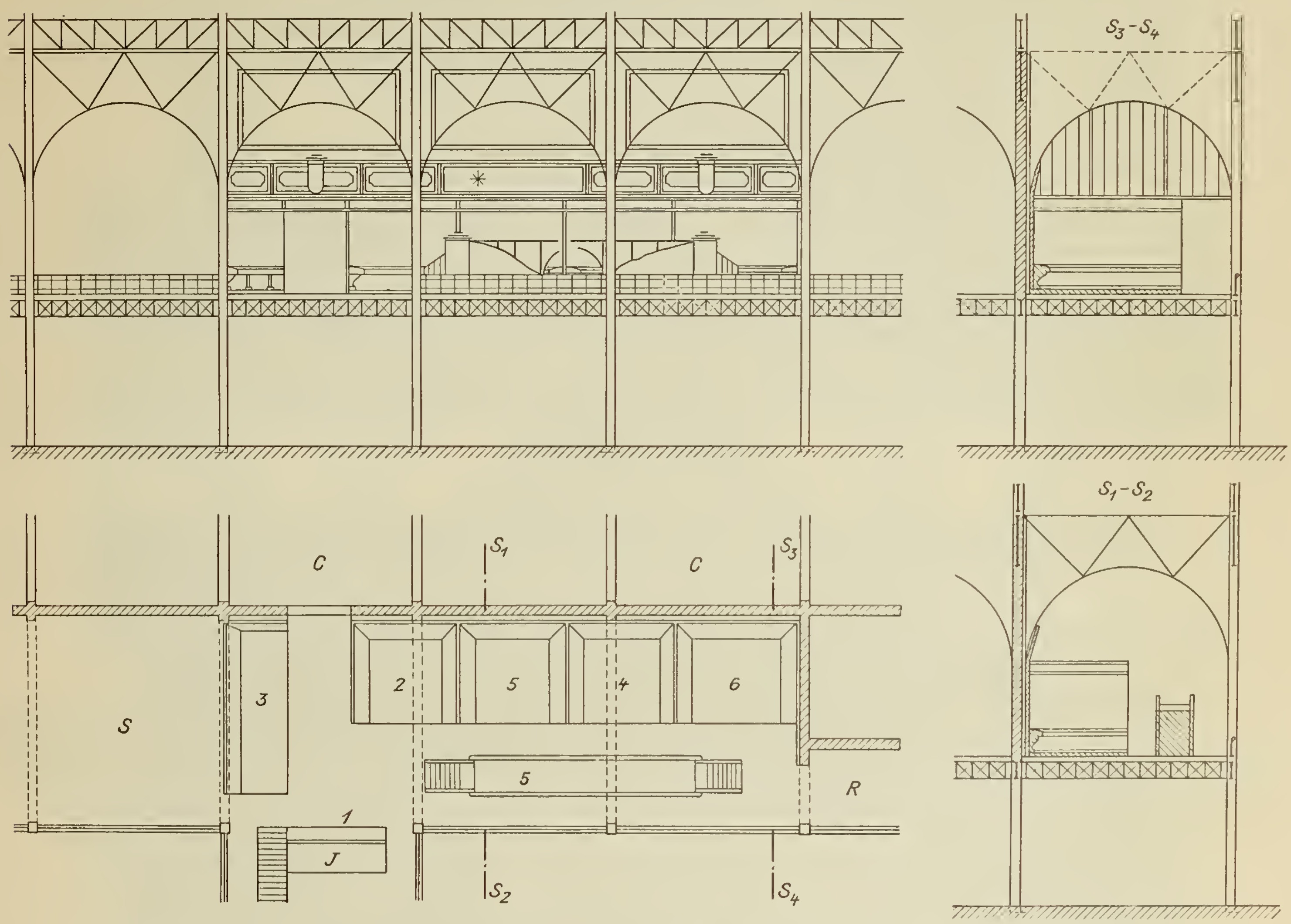
The iron structure contains:

about 3000 tons of mild steel.
- 127 - - cast iron,
- 55 - - cast steel.

The platform consists of buckled plates, carrying the wood pavement on concrete. The footpaths are formed of concrete flags on iron flooring, with a cover of concrete and asphalte. At the first three panels the platform is fixed immediately to the main verticals, while in the remaining panels it is suspended from the arch by means of tie-rods, forming a continuation of the verticals.

The centre span is provided with *two windbracings*, for arch and platform respectively. The former in case of the two panels adjoining the springing is placed at the level of the bottom flange, while in the remaining panels it is at the top flange of the arch.

Fig. 172. Plan and sections of the Exhibition Rooms of German Bridgeworks at Paris. 1900.



1. Esslingen Works. 2. Harkort Co. 3. Ph. Holzmann & Co. 4. Gutehoffnungs Works. 5. Nuremberg Works. 6. Union Works. J. Professor Intze. R. Russia. S. Sweden. C. Arcades.

In April 1896 work was commenced at the foundation of the two river piers. Between spring 1897 and the end of 1897 the iron structure of the centre span was erected. At the same time the foundation of the two abutments was being proceeded with, so that in autumn 1898 the erection of the two side spans could be finished. During the winter months of 1897—98 the Wharfs on the Rhine were bridged over, and on December 17, 1898, the bridge could be opened for traffic.

The pier foundations consist of concrete between coffer dams, the latter being made of iron joists, reaching to 4 metres (13′ 1″) below the bottom of the concrete bed in case of the river piers, 3 metres (9′ 10″) at the abutments. The concrete itself at the river piers extends to 5 metres (16′ 5″) below the river bed, at the Bonn abutment 4 metres (13′ 1″) and at the Beuel abutment 3,5 metres (11′ 6″).

The two windbracings are connected by means of the *portal* (see figures 173 and 174), designed as a stiff frame enclosing both top- and bottom flange. The windbracing of the platform, being provided with flanges of its own, could not be continued uninterruptedly over the entire length of the central arch, because in that case it would have been affected by the horizontal thrust of the latter. For this reason it was made to act as a horizontal cantilever structure, supported at the portal by the windbracing of the arch as well as by the piers in a manner allowing small deformations in a longitudinal direction. The windbracing itself is represented partly by the buckled plates of the platform, partly by special wind diagonals between the bottom flanges of the crossgirders.

The side spans, too, are provided with two wind girders, the upper one being at platform level, the lower between the bottom

Fig. 173. East Portal of the Rhine Bridge at Bonn.

Fig. 174. West Portal of the Rhine Bridge at Bonn.

flanges. The top flanges of the arches at the same time form the flanges of the upper wind girder, while its web is represented by the buckled plates. The lower windbracing has horizontal posts and diagonals.

Fig. 175. Railings of the Rhine Bridge at Bonn.

Fig. 175 a.

Fig. 175 b.

Fig. 176. Details of Railings.

Fig. 176 a.

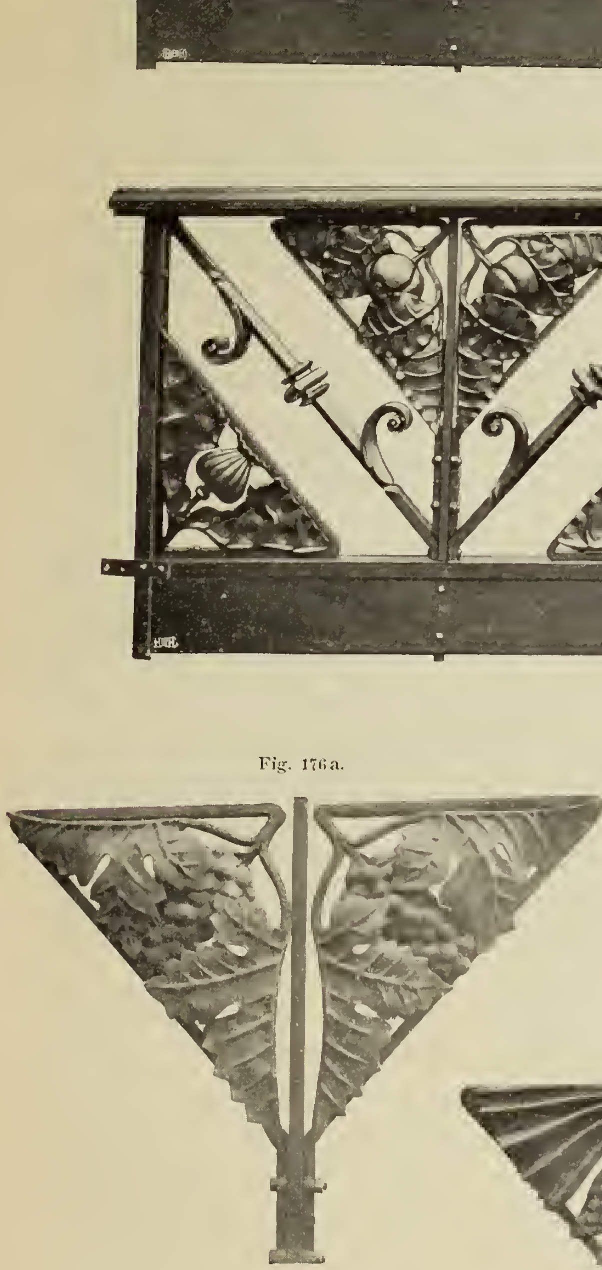


Fig. 176 b.

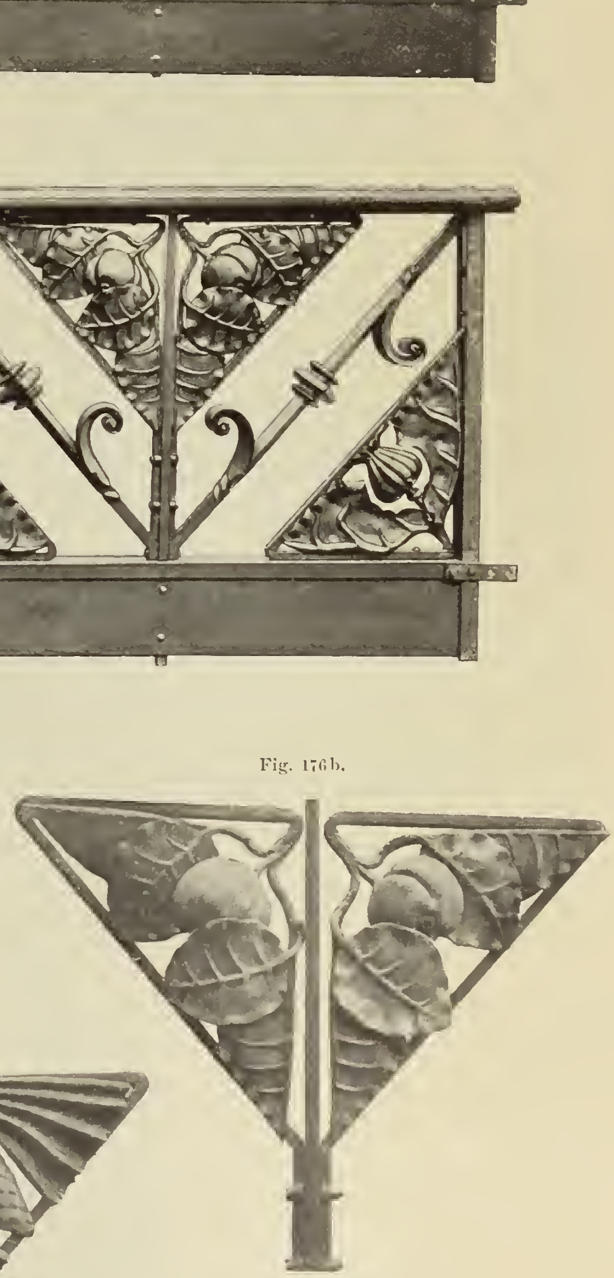
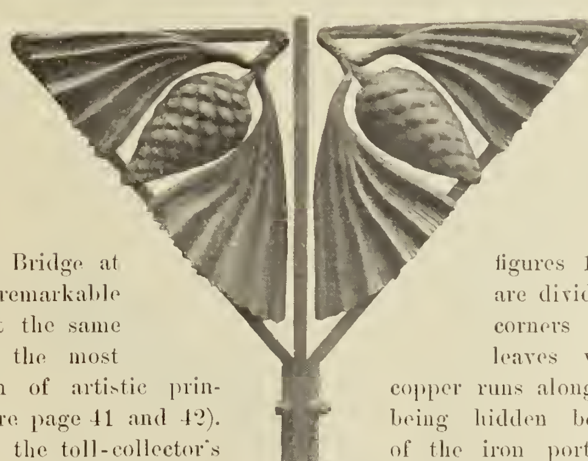


Fig. 176 c.



In the author's opinion the Rhine Bridge at Bonn not only represents a structure remarkable from an engineer's point of view, but at the same time deserves to be classed among the most successful examples of the application of artistic principles to modern bridge building (compare page 41 and 42). The details of the tower-like piers, of the toll-collector's boxes, as well as those of the ornamental parts of the iron structure are of an unusually artistic and elaborate character, occasionally giving expression to the well known "Rhenish" sense of humour (see figures 69 and 173 to 178). The river piers are provided with tower-like buildings of the Romanesque style of architecture, the toll-collector's boxes on the abutments showing details of a similar character. The ornamental design of the railings is of particularly pleasing effect (see figures 175 and 176). Their rectangular panels are divided by diagonal bars with scroll-work, the corners being filled up with flowers, fruit and leaves worked in iron. A moulding of chased copper runs along the bottom of the railing, the brackets being hidden behind iron dragons. The flat surfaces of the iron portals are covered with embossed work on iron or copper, representing different subjects in an allegoric manner. The ornamental ironwork has been made by Messrs. *Hillerscheid & Kasbaum* of Berlin.

Fig. 177—178. Details of Lamps on the Rhine Bridge at Bonn.

Fig. 177 a.

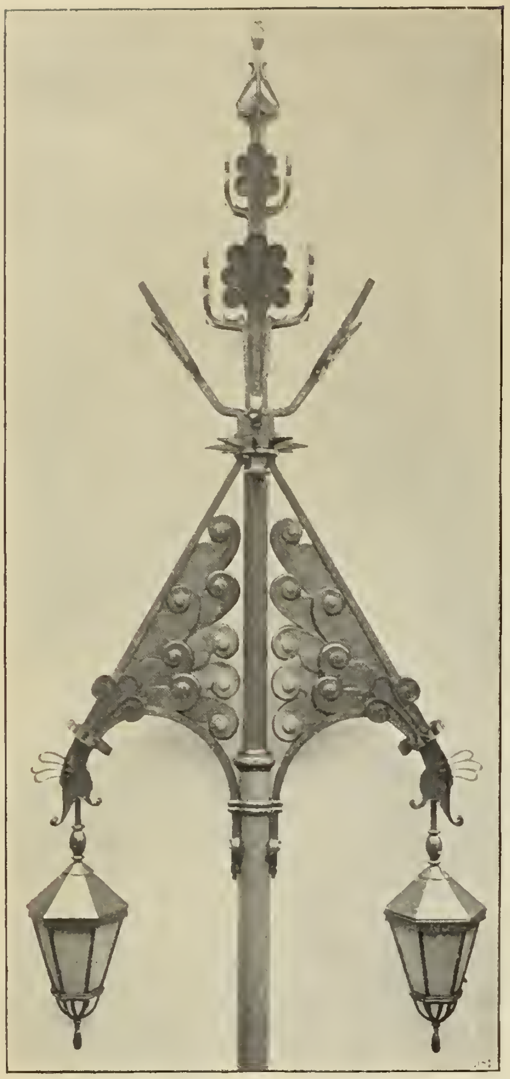


Fig. 177 b.

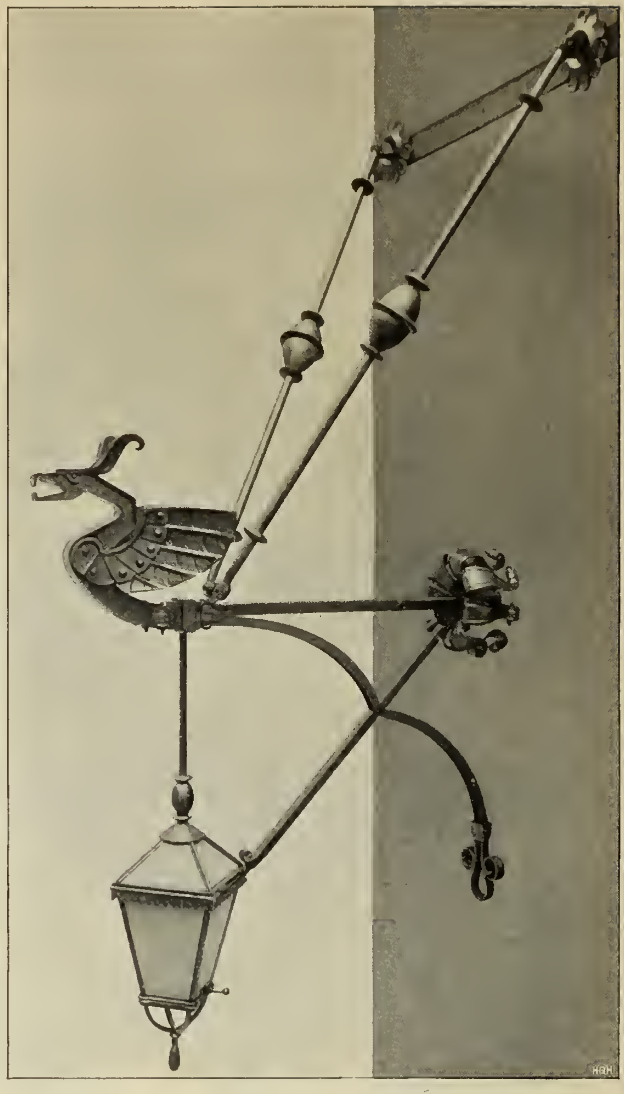


Fig. 178.

b) Left-hand side.

6. *Roadbridge over the Rhine at Düsseldorf.* 3 water-colour sketches and a drawing. — Compare fig. 106.

Owners: The Rhenish Railway Company at Düsseldorf.

Designers: The Gutehoffnungs Works. Professor A. Schill, architect, of Düsseldorf.

Builders: Piers by Philipp Holzmann & Co., Frankfort-on-Main. Iron superstructure by the Gutehoffnungs Works.

Date of erection: 1896 to 1898.

Description:	*weight*
2 river spans of 181,25 metres (595 feet) each,	3530 tons
3 left-hand tide spans of 63,36, 57,024 and 50,68 metres (208, 187 and 166 feet) respectively,	1005 -
1 right-hand tide span of 60,36 metres (198 feet),	380 -

The platform of the bridge is 14,20 metres (46′ 6″) wide, viz. roadway 8,20 metres (26′ 10″) and footpaths 3,0 metres (9′ 10″) each.

River spans: Elastic arches with hinges at the springing.

Tide spans: Elastic arches with hinges at the springing and braced spandrels.

The *Rhine Bridge at Düsseldorf* carries a road as well as the Düsseldorf and Crefeld Electric Railway. The foundation of the piers was commenced in July 1896. In 1897, after the high spring tides has subsided, the scaffolding for the left-hand main span was put up, and already on October 1st of the same year the arched girders with platform suspended were resting on the piers. The right-hand abutment as well as the intermediate river pier of the main spans had to be provided with pneumatic foundations, while those of the piers on shore were built between timber coffer-dams. The favourable weather prevailing during the winter of 1897—98 made it possible to finish the portal building of the right-hand abutment as well as the three left-hand side spans. In 1898 after completing the left-hand shore- and river pier the right-hand main- and side spans were erected. At the same time the platform and the left-hand approach roads were completed in time to open the bridge for traffic on November 12, 1898. The time of erection, therefore, did not exceed $2^1/_2$ years.

With regard to the design of its superstructure (see fig. 106) the Düsseldorf Bridge on the whole is similar

to that at Bonn described before. The portal buildings are designed in a simple but dignified Renaissance style of architecture by Professor *Schill* of the Royal Academy of Arts at Düsseldorf; on the up-river side of the central pier a powerful lion, carrying anchor and escutcheon, is keeping guard.

About 4700 tons of mild steel,
- 190 - - cast iron,
- 100 - - cast steel

have been used for the iron superstructure.

c) Right-hand side.

7. *Roadbridge over the Aare at Berne.* 3 water-colour sketches and a drawing. — Compare fig. 179.

Owners: Municipal board of works at Berne.

Designers: The Gutehoffnungs Works. Th. Bell & Co., engine factory at Kriens. P. Simons, builder, Berne. A. & H. von Bonstetten, civil engineers, Berne. B. H. von Fischer, architect, Berne, after a preliminary design by the board of works at Berne.

Builders: P. Simons of Berne, for piers. The Gutehoffnungs Works for the ironwork of the main span. Th. Bell & Co., Kriens, for the ironwork of the side spans.

Date of erection: 1895 to 1898.

Description:	*weight*
1 main span of 114,858 metres (377 feet)	905 tons
5 side spans of 34,42 metres (113 feet) each,	915 tons
2 - - - 15,50 - (51 feet)	

Width of platform 12,6 metres (41′ 4″), viz. roadway 7,2 metres (23′ 8″) and footpaths 2,7 metres (8′ 10″) each.

Main span: Stiff arch.

Side spans of 34,42 metres: Two-hinged plate arches.

Side spans of 15,50 metres: Parallel-girders.

In addition a number of photographs of larger structures built by the Gutehoffnungs Works, as well as small photo albums and plans with descriptions of the works are exhibited on either side.

III. Gesellschaft Harkort (Harkort Company) at Duisburg-on-Rhine.

a) Front.

8. *Lighthouse on the Rothersand in the North Sea.* Erected in the open sea, 50 kilometres (31 miles) from Bremerhaven in the direction of Heligoland. Illustrated by a water-colour drawing and one working drawing each of the floating caisson and the finished structure. — Compare figures 180 and 180a.

Owners: The states bordering on the Weser, viz. Prussia, Oldenburg and Bremen.

Fig. 179. Roadbridge over the Aare at Berne. 1898.

Building Department: The State of Bremen, representing the states named above.

Charged with the supervision of the building operations: The late Baurath *Hanckes* and Regierungs-Baumeister *Körte* of Bremerhaven.

Designers: Exterior, interior arrangement and fittings, by the Building Department; manner of foundation and the entire erection with all arrangements, plant and machinery required, by the Harkort Company at Duisburg (Mr. *Seifert*, chief engineer).

Builders and contractors: The Harkort Company at Duisburg.

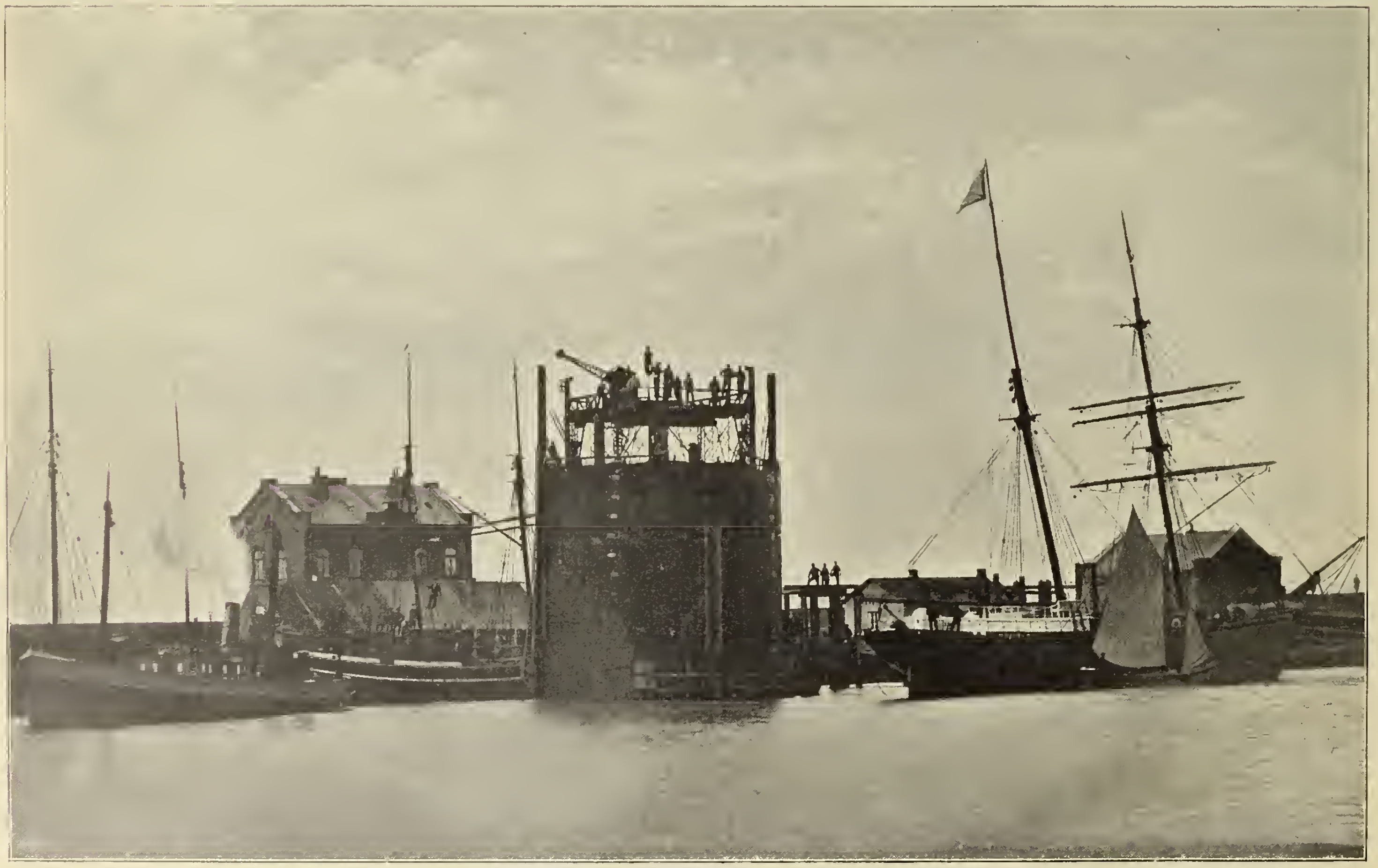
Date of erection: Autumn 1882 to autumn 1885.

Description: The pneumatic foundation of the lighthouse extended to a depth of 22 metres (72 feet) below L. W. or 25 metres (82 feet) below Mean H. W. The iron caisson was put together afloat in the Kaiserhafen at Bremerhaven, provided with all

machinery and appliances required for submerging it, then floated out to the site in open sea by tugs (see fig. 180a) and submerged by letting in water. The sinking by compressed air as well as the concreting and walling up of the caisson was done in a manner

Fig. 180. Lighthouse on the Rothersand in the North Sea. 1885.

Fig. 180a. Floating out to sea the iron caisson of the Rothersand Lighthouse.



similar to that applied in building bridge piers, with the only exception that no *scaffolding* whatever could be used. For this reason special plant had to be designed and manufactured for the purpose. The lack of any space for storing materials, the difficulties of transport, the housing and feeding of a good many workmen on special ships provided for the purpose, further the measures of safety required to protect the unfinished structure against the dangers of the high sea for a period of several years, the site being in the most exposed part of the North Sea, all this suffices to *render the erection of this building a matter of the highest interest to engineers.*

Dimensions, quantities and weights of the structure.

Height of caisson	24	metres	(78′ 9″)
Height of lighthouse proper .	33	-	(108′ 3″)

Total height from cutting edge of caisson to top of tower 33 + 24 = ...	57 metres	(187′ 0″)
Area of foundation (lens-shaped)	115 sq. metres	(1238 □′)
Large diameter of lens . .	14 metres	(45′ 11″)
Small - -	11 -	(36′ 1″)
Plan of lighthouse proper is circular, with sides slightly curved and conical.		
Diameter at bottom . .	10,3 metres	(33′ 9″)
- at level of keeper's room .	5,1 -	(16′ 9″)
- of lantern . . .	3,3 -	(10′ 10″)
- of the 3 jutties	2,0 -	(6′ 7″)
Excavation by compressed air	950 cubic metres	(1243 cubic yards)
Masonry and concrete . . .	2800 - -	(3662 - -)

Fig. 181. The do Chá Viaduct for São Paulo, Brazil, as erected at the Harkort Company's Bridge Works, Duisburg. 1890.

Weight of iron (in permanent structure)	500 tons	
Fascines for securing the bottom of the sea near the site . .	5000 cubic metres	(6540 cubic yards)
Ballast used for weighting the fascines	600 - -	(786 - -)

A paper entitled *"The Rothersand Lighthouse in the North Sea"* in *German, French or English* will be sent free of charge, on written application to the Harkort Company at Duisburg-on-Rhine or its representative at the exhibition.

b) Right-hand side.

9. *Double line Railway Bridge over the Rhine at Worms,* on the Worms, Rosengarten and Darmstadt line. Illustrated by 1 water-colour drawing of the finished structure and 3 working drawings of the central river span of 116,2 metres (381 feet), representing: View and plan of the maingirder sand platform; sections near the centre at node 8 and at node 1; end portal at node 0 — Compare fig. 110.

Owners and Building Department: The Royal Prussian and Grandducal Hessian Railway Board at Mayence.

Charged by the state with the supervision of the erection: Mr. *Geibel*, Worms, Grandducal Hessian inspector of railways.

Designers: The Harkort Company at Duisburg-on-Rhine in cooperation with Mr. *G. Frentzen*, architect, of Aix-la-Chapelle, and R. Schneider, a firm of builders at Berlin. The bridge is the outcome of a competition, the Harkort Company being awarded first prize among 5 competitors.

Builders: The Harkort Company, for the pneumatic foundation of the two river piers and the whole of the ironwork; R. Schneider of Berlin for the piers (foundation excepted) and all piers on shore; architecture by Mr. *Hofmann*, Stadtbaurath, of Worms.

Date of erection: 1898 to 1900.

Description: The 3 river spans, carrying a double line of railway, are provided with tied braced arches and a *freely suspended platform on the Harkort Company's system,* as shown in detail and described on page 90 to 92.

The 17 tide spans are bridged over by 34 braced girders with parallel flanges and platform on top, carrying a single line of railway.

Starting from the left-hand shore, the whole structure consists of:

1 side river span of 102,2 metres	(335 feet)	= 858,5 tons
1 central - - - 116,8 -	(383 feet)	= 1059,0 -
1 side - - - 102,2 -	(335 feet)	= 858,5 -
17 tide spans of 34,5 metres (113 feet), weighing 78,1 tons each		= 2655,4 -
	Total weight	5431,4 tons

For the pneumatic foundation of the two river piers caissons of an area of 156 square metres (1679 square feet) were sunk about 12 metres (39′ 4″) below L. W. The abutments and shore piers have concrete foundations between coffer-dams.

c) **Left-hand side.**

10. *Pin Bridges for exportation.* On the Harkort Company's own system, as shown in figures 127 to 136 and described on pages 84 to 87. Illustrated by 1 water-colour drawing of the Soengei-Oelar Bridge on Sumatra, in course of erection; 1 photograph, from which this drawing was made; another photograph of the same bridge; 1 working drawing of the Soengei-Oelar Bridge, showing view, section, plan and manner of erection; 1 working drawing of the do Chã Viaduct in São Paulo, Brazil, showing view, section, plan of the main spans and the whole arrangement of the structure.

a) *The Soengei-Oelar Bridge.* Single line Railway Bridge over the Soengei-Oelar river on Sumatra.

untrained coolies, directed by two Europeans. The number of pieces, sent out separately to build up a bridge of this kind, is the smallest possible.

b) *The do Châ Viaduct in São Paulo, Brazil.* Road-bridge with timber floor, 13,6 metres (44′ 8″) wide. — Compare fig. 181.

Owners and Building Department: The São Paulo city authorities.

Designers: The Harkort Company as above (see a).

Description:

The bridge consists of:

1 span of 16,5 metres (54′ 1½″), weighing	36,4 tons
4 spans of 33 metres (108′ 3″), weighing 82,3 tons each	329,2 -
3 iron piers, weighing	49,8 -
Total weight	415,4 tons

Fig. 182. Bridge over the Vaal River near Standerton, Transvaal. 1890.

Owners and Building Department: The Deli-Spoorweg-Maatschappy on Sumatra, Mr. Tromp, Amsterdam, chief manager.

Designed and built: by the Harkort Company of Duisburg, on their own system of pin bridges.

Description: The bridge consists of one span of 61,5 metres (202 feet), weighing 135,7 tons. The maingirders are of the parabolic type, with verticals and single diagonals of a section designed to resist compression as well as tension. The top flange is formed of ready made pieces of panel-length, the bottom flange of eyebars of similar length. The crossgirders are sent out in one piece and fixed to the verticals by means of 4 bolts and 2 wedges. The railbearers (also shipped in one piece) rest on brackets fixed to the crossgirders and are connected to the latter by bolts. The windbracings partly consist of eyebars, partly of diagonals with pin connections. Not a single rivet need, therefore, be inserted at the erection, and no smith's work whatever is required. The entire erection was accomplished within 15 days by 37 perfectly

Each span has 3 maingirders with parallel flanges and a single set of stiff diagonals, carrying on top the crossgirders, extended beyond the maingirders as cantilevers. The longitudinal platform girders consist of iron joists. — The oaken bridge floor is formed of cross beams, carrying longitudinal planks with cross planking on top. The footpaths are provided with longitudinal planking on cross beams.

The columns of the iron piers are formed of four quadrant irons each; they, too, are fixed together by means of bolts and screws in order to be able to dispense with any smith's and rivetting work at the erection.

Further particulars regarding the Harkort Pin Bridge System will be readily communicated on written application to the Harkort Company at Duisburg-on-Rhine.

d) **Desks at the partition walls.**

On these desks 15 framed photos and 2 photograph albums are on view.

The framed photographs represent (from right to left):

1. Bridge over the Elbe at Hamburg, Germany (see fig. 46).
2. Bridge over the Rhine at Coblenz, Germany (see fig. 42).
3. Bridge over the Leek at Kuilenburg, Holland (see fig. 30).
4. Exhibition Palace at Vienna, Austria, in 1873.
5. Emperor Francis Joseph-Bridge at Vienna, Austria.
6. Bridge over the Götha-Elf near Trollhättan, Sweden.
7. Velanda Viaduct near Velanda, Sweden.
8. Bridge over the Minnesund near Minne, Norway (see fig. 158).
9. Bridge over the Msta near Werebia, Russia.
10. Bridge over the Argesch near Pitest, Roumania.
11. Bridge over the Ave at Villa do Conde, Portugal.
12. Tenjin-bashi at Osaka, Japan.
13. River stockade at Whampoa, China.
14. Bridge over the Vaal River near Standerton, Transvaal (see fig. 182).
15. Bridge over the Sorocaba River near Sorocaba, Brazil.

The Album Nr. V, entitled: "Brücken und andere Eisenkonstruktionen" ("Bridges and other Ironwork"), contains drawings of bridges, railway wagons and other structures *in Europe.*

Owners: The Grandducal Ministry of Finances at Darmstadt, represented by *Dr. Th. Schäffer*, Ministerialrath, and the late Oberbaurath *Pfarrer.*

Designers: The late Bernhard *Bilfinger* of Pforzheim and *W. Lauter* of Frankfort-on-Main, engineers, and *F. Thiersch* of Munich, architect. The design received first prize in the public competition (see page 41).

Builders: The piers were built by the exhibiting firm, represented by its chief engineer, Mr. *W. Lauter.* The iron superstructure was made by Benkiser Brothers of Pforzheim, under the directions of Mr. *Bilfinger*, their engineer.

Date of erection: 1881 to 1885.

Description: The bridge, 499 metres (1637 feet) long between the abutments, crosses the Rhine in 5 spans of 87,99, 103,99 and 87 metres (289, 341 and 286 feet) respectively. Each span is supported by 4 elastic arches, placed entirely below the platform and provided with hinges at the springing. The roadway, 7,8 metres (25′ 7″) wide, as well as the two footpaths, each 3 metres (9′ 10″) wide, rising in a parabolic curve from both shores towards the centre, are carried by a system of longitudinal and crossgirders. On the left-hand shore there are two additional openings, consisting of masonry arches of 10 and 17,5 metres (32′ 9″ and 57′ 5″) span, while on the right-hand shore there is another 10 metres (32′ 9″) span.

The 4 river piers, 8,6 metres (28′ 3″) wide at Mean Water, as well as the left-hand shore pier, are built over iron caissons, 9,5 metres (31′ 2″), by 24,33 metres (79′ 10″) and 8 by 18 metres (26′ 3″ by 59′ 1″) respectively, sunk by the pneumatic method. The bottom part of the caisson is filled up with concrete, its water-tight lining being inside. The remaining piers and the abutments are built on brick-lined shafts. — The total contract sum amounted to 3 208 000 Marks (£ 160 400).

Fig. 183. Bridge over the Bindjey River on Sumatra. 1890.

The Album VI entitled: "Gelenkbrücken für den Export" ("Pin Bridges for Exportation") exclusively illustrates bridges on the Harkort Company's Pin System *as sent abroad*, consisting partly of photographs taken at the erection, partly at the works, both put in juxtaposition wherever possible. An example from Sumatra is shown in fig. 183.

IV. Baugesellschaft Ph. Holzmann & Cie. (Ph. Holzmann Co., Ld., Builders), Frankfort-on-Main.

11. *Rhine Bridge between Mayence and Castel.* Illustrated by a picture, 26 feet long, near the entrance to the German Engineering Exhibition, further by 3 water-colour drawings and 3 plans. A drawing, 3′ 7″ high and 14′ 9″ long, shows a perspective view of the entire structure, together with part of the city of Mayence. On the left of this a perspective of one of the river spans is on view, on the right a drawing showing the architectural part of a river pier. Below the large painting there is a longitudinal section of the bridge in 1 to 150, representing the central part, 700 metres (2300 feet) long, of its whole length of 985 metres (3228 feet). On the left and right of this details of the ironwork are shown.

12. *Diving-Bell for the Drydocks at Kiel.*

The *Diving-Bell* required for building two drydocks at Kiel, each 30 metres (98 feet) wide, 175 metres (574 feet) long and 11 metres (36 feet) deep at Mean Water, is shown in longitudinal and cross section (scale 1 : 50) on two drawings, to be found on the partition wall, 10 feet long, near the entrance of the German Engineering Exhibition (see fig. 172).

Owners: The Imperial Navy.

Designer: Mr. *K. Sonntag*, engineer to the firm of Ph. Holzmann & Co.

Builders: The ironwork was made and erected by the Gutehoffnungs Works, the lift by Haniel & Lueg, the electric plant by the Elektricitäts-Aktien-Gesellschaft, late W. Lahmeyer & Co., all according to instructions received from and under directions of Philipp Holzmann & Co.

Description: The dimensions of the diving-bell are as follows:
Width . . . . 14 metres (45′ 11″)
Length . . . . 42 - (137′ 10″)
Height of working space . . . 2,5 - (8′ $2\frac{1}{2}$″).

The fittings of the diving-bell consist of a suspension frame carried by 2 iron barges, 2 air chambers for workmen, 1 for concreting, 2 (provided with an electric lift) for other materials, 3 electric cranes, 2 concrete mixers worked by electro-motors and producing 400 cubic metres (523 cubic yards) of concrete an hour. — The probable time of construction of the two drydocks with the aid of the diving-bell will be three years, viz. from 1900 to 1903. — The diving-bell has already been completed and is in full working order.

13. *Pneumatic Foundations by Philipp Holzmann & Co., Ld., of Frankfort-on-Main.* A table containing full particulars will be found above the drawing: "Taucherglocke für das Trockendock Kiel" ("Diving-Bell for the Kiel Drydocks").

Built entirely in quick-sand, with the aid of a shield, worked by compressed air and patented by the company named above, the shield being of a similar shape to that proposed by *Baudirektor Mackensen* in his patents, bought up by the company.

Time of construction: Including all preliminary trials, construction of shield and other plant, etc., 2 years. 1896 to 1898.

A full *description* will be found in the paper: "Der Spreetunnel zwischen Stralau und Treptow bei Berlin". Berlin, published by Julius Springer. 1899. —

V. Vereinigte Maschinenfabrik Augsburg und Maschinenbau-Gesellschaft Nürnberg A.-G. Werk Nürnberg (United Augsburg and Nuremberg Engine Works, Ld., Nuremberg Works).

a) Front.

15. *Roadbridge over the Rhine at Worms.* 2 water-colour and other drawings. — Comp. figures 184 and 185, also 70 and 109.

Pneumatic Foundations by Philipp Holzmann & Co., Ld, Frankfort-on-Main.

Number	Description of building	Built in	Caissons: Number	Caissons: Maximum area in square metres	Caissons: Maximum area in square feet	Caissons: Material	Greatest air pressure in atmospheres	Total excavation with the aid of compressed air: cubic metres	cubic yards	Cost and extent of work contracted for by Philipp Holzmann & Co., Ld.: Marks	£	Extent of contract
1	Wettstein Bridge over the Rhine at Basle.	1879	2	163	1755	Iron	2	1800	2354	1 469 000	73 450	Entire structure
2	Johanniter Bridge over the Rhine at Basle.	1881	6	122	1313	-	$2\frac{1}{4}$	6300	8240	1 295 000	64 750	- -
3	Aar Bridge near Olten.	1882	2	36	388	-	2	500	654	99 000	4 950	Piers and abutments
4	Quay Bridge over the Limmat at Zürich.	1883	1	61	657	Timber (Diving-bell)	2	—	—	700 000	35 000	Entire structure
5	Rhine Bridge at Mayence.	1885	5	207	2228	Iron	$2\frac{1}{2}$	7100	9281	3 208 000	160 400	- -
6	Weser Bridge near Holzminden, Brunswick.	1885	2	33	355	-	2	500	654	306 000	15 300	- -
7	Main Bridge at Kostheim (near Mayence).	1889	2	84	904	Timber	2	800	1046	826 000	41 300	- -
8	Dievenow-Bridge at Wollin, Pommerania.	1891	6	54	581	Iron and stone	$2\frac{1}{2}$	1700	2224	184 000	9 200	Piers and abutments
9	King Charles-Bridge over the Neckar at Kannstadt.	1892	4	172	1851	Iron	2	5200	6802	241 000	12 050	- -
10	Carola Bridge over the Elbe at Dresden.	1892	2	335	3606	-	$2\frac{1}{2}$	4100	5363	450 000	22 500	- -
11	3 Swingbridges over the North Sea-Baltic Canal.	1894	6	71	764	Iron and stone	$2\frac{1}{4}$	3300	4316	650 000	32 500	- -
12	Crown of lock 85, Rhine-Rhône Canal.	1894	1	115	1238	Iron	$1\frac{1}{2}$	500	654	85 000	4 250	Substructure
13	Oder Bridge at Frankfort.	1895	8	82	883	Timber	3	6500	8502	994 000	49 700	Entire structure
14	Spree Bridge at Treptow near Berlin.	1895	2	71	764	-	2	1100	1439	108 000	5 400	Piers and abutments
15	Arda Bridge near Adrianople.	1895	1	26	280	Iron	2	200	262	400 000	20 000	- -
16	Weser Bridge near Stolzenau, Hanover.	1896	2	60	646	Iron and stone	2	800	1046	157 000	7 850	- -
17	Weidendamm Bridge over the Spree, Berlin.	1896	1	42	452	Timber	$1\frac{3}{4}$	200	262	153 000	7 650	- -
18	Rhine Bridge at Strassburg in Alsace.	1897	6	96	1033	Iron	$3\frac{1}{4}$	9100	11903	748 000	37 400	- -
19	Inn Bridge at Mühldorf, Bavaria.	1897	1	74	797	Timber	2	500	654	130 000	6 500	- -
20	Alz Bridge at Burgkirchen, Bavaria.	1897	2	48	517	Iron	$1\frac{3}{4}$	1100	1439	107 000	5 350	- -
21	Warthe Bridge at Landsberg.	1897	4	65	700	Timber	$2\frac{1}{4}$	2100	2747	242 000	12 100	- -
22	Oder Bridge at Ohlau, Silesia.	1898	2	68	732	Iron and stone	$2\frac{1}{2}$	900	1177	76 000	3 800	- -
23	Rhine Bridge at Düsseldorf.	1898	2	434	4672	Iron	$2\frac{1}{2}$	5500	7194	1 629 000	81 450	- -
24	Oder Bridge at Stettin.	1899	4	170	1830	Timber	$2\frac{3}{4}$	3200	4186	610 000	30 500	- -

14. *The Spree Tunnel at Berlin on the Stralau-Treptow line of the Berlin Eastern Tramways.*

The tunnel is shown in 10 coloured drawings on the partition wall near the entrance to the German Engineering Exhibition.

Owners: *"Die Gesellschaft für den Bau von Untergrundbahnen G. m. b. H."* (Company for building Underground Railways, Ld.) of Berlin, formed by the financial groups of the Deutsche Bank, Berlin, the Allgemeine Elektricitäts-Gesellschaft, Berlin, and Philipp Holzmann & Co., Ld., of Frankfort-on-Main. After the death of Mr. *Schnebel,* Regierungs- und Baurath, of Berlin, the company is managed by *chief engineer Lauter* of the firm of Philipp Holzmann & Co.

Building Department: Grandducal Hessian Ministry of Finances.

Designers: Nuremberg Engine Works, Ld., Messrs. Grün & Bilfinger, builders, of Mannheim; Geh. Oberbaurath *Hofmann* of Darmstadt, architect.

Builders: The *"Bauunternehmung für die Strassenbrücke Worms"* (The Worms Bridge Building Co., Ld.), specially formed for the purpose by the Nuremberg Engine Works, Ld., and Messrs. Grün & Bilfinger, builders.

Date of erection: 1897 to 1900.

Description: 2 river spans of 94,4 metres (310 feet) each and 1 river span of 105,6 metres (346 feet). Weight 1800 tons. Platform on top. — 9 right-hand and 3 left-hand arched tide spans of 35

to 21 metres (115 to 69 feet). 1 arch of 18 metres (59 feet) span, crossing the road running along the river bank. River spans: Crescent-shaped arches with 2 hinges. Tide spans: Concrete arches with 3 hinges each (made of lead).

b) Right-hand side.

16. *Elevated Railway Rittershausen - Barmen - Elberfeld-Vohwinkel,* on Eugen Langen's patented system (the train being suspended from one rail), 13,3 kilometres (7,3 miles) long, 10 kilometres (6,2 miles) being situated above the Wupper River. — Comp. fig. 186 to 188.

Owners: Continentale Gesellschaft für elektrische Unternehmungen and *Elektricitäts-Aktiengesellschaft vorm. Schuckert & Co.* at Nuremberg.

Designers of ironwork: Gustavsburg Branch of exhibiting firm.

Builders: Gustavsburg Branch of exhibiting firm in connection with the Gutehoffnungshütte at Oberhausen, the Harkort Company at Duisburg and the Union Works at Dortmund.

Date of construction: 1898 to 1902.

iron structure specially designed for the purpose (see fig. 188), because during the high tides occurring in December, January and February fixed scaffolding cannot be left in the river bed. The structure referred to, being 69 metres (226 feet) long, is provided with winding-engines and can be shifted by means of rollers, subjected to a surface pressure of 170 kilos per square centimetre (1,08 tons per square inch). The girder is being moved forward on the finished part of the elevated railway a distance sufficient for the erection of the next arch, the latter being carried to the spot on specially built cars running on the finished structure. As soon as the arched pier has been thus put up with the aid of cranes, the erecting girder is lowered down so as to rest on it, and the next longitudinal girder can be carried forward and fixed in its turn.

c) Left-hand side.

17. *Roadbridge over the Danube at Straubing.* 1 water-colour and 1 other drawing. — Comp. fig. 104.

Building Department: Royal Bavarian Board of Roads and Rivers at Deggendorf.

Designers: The Board named above and the Gustavsburg Branch of the Nuremberg Engine Works, Ld.

Builders: Gustavsburg Branch of exhibiting firm.

Fig. 184. Nuremberg Works. Roadbridge over the Rhine at Worms. 1900.

Description: Iron Viaduct, 13,3 kilometres (7,3 miles) long, divided into spans of 24, 27, 30 and 33 metres (79, 89, 98 and 108 feet) respectively. Main (longitudinal) girders of special system (Impl German Patent Nrs 91 642 and 96 200), supported on two-hinged arches of different design for river- and ordinary spans; main- and rocker-piers, the former being about 200 metres (656 feet) apart. *Total weight* of ironwork 18 000 tons. Two maingirders of 30 metres (98 feet) span each are on view at Vincennes in full size. The smallest radius of the curves is fixed at 90 metres (295 feet), the maximum gradient at 45 in 1000. It is believed that a speed of 40 kilometres (25 miles) an hour will be attained without difficulty. Taking into account that only 15 seconds are required from starting the train to full speed, it appears probable that the average speed will be about three times that of ordinary electric tramcars.

The greatest difficulty to be surmounted proved to be the question of points and sidings, a number of which necessarily had to be provided along the line, because otherwise the heavy traffic between Barmen and Elberfeld would have to be continued to Vohwinkel, and further because any damaged car could not be replaced without disturbing the regular traffic. 10 kilometres (6,21 miles) of the iron structure are situated immediately above the Wupper river, 3 kilometres (1,86 miles) being above roads. The Harkort Company, the Gutehoffnungs and Union Works began by building up fixed scaffolding for the erection of the spans above the river, while the Nuremberg Company made use of an

Date of erection: 1895 to 1896.

Description: River span: Crescent-shaped arch of 91 metres (298 feet) span with 2 hinges, platform below. 1 tide span (masonry arch) of 8 metres (26′ 3″) on either side; weight 370 tons.

18. *Roadbridge over the Southern Elbe at Harburg.* 1 water-colour and 2 other drawings. — Comp. figures 47 and 48.

Owners: The city of Harburg and the parish of Wilhelmsburg.

Supervision of erection: The Royal Prussian Inspector of Hydraulic Works at Harburg.

Designers: The Nuremberg Engine Works, Gustavsburg Branch: Mr. *C. O. Gleim* C. E., of Hamburg, and Mr. *Thielen,* architect, of Hamburg.

Builders: The Gustavsburg Branch of the exhibiting firm.

Date of erection: 1897 to 1899.

Description: 4 river spans of 100,96 metres (331 feet) each, weighing 2060 tons; 6 tide spans of 31,15 metres (102 feet) each, weighing 540 tons. River spans: Tied braced arches with platform below. Tide spans: Girders with parallel flanges and platform on top.

19. *Swingbridge over the Reiherstieg at Neuhof, Hamburg.* 1 water-colour and 1 other drawing.

Owners: Aktien-Gesellschaft Neuhof (Neuhof, Ld.).

Supervision: Royal Prussian Inspector of Hydraulic Works at Harburg.

Designers and builders: The Nuremberg Engine Works, Ld., Gustavsburg Branch.

Fig. 185. Nuremberg Works. Portal of the Roadbridge over the Rhine at Worms.

Date of erection: 1898 to 1899.

Description: Continuous braced girders with two spans of 24,2 and 50,8 metres (79 to 167 feet) respectively. Platform below. Weight including machinery 360 tons. Worked by benzene-motor.

20. *Single line Railway Bridge over the Weser at Minden.* 1 water-colour and 1 other drawing.

Owners: The County of Minden commission for light railways.

Building Department: Board of the Minden County Railways.

Designers and builders: The Nuremberg Engine Works, Ld., Gustavsburg Branch.

Date of erection: 1897 to 1898.

Description: 1 river span of 67 metres (220 feet), weighing 170 tons. 14 tide spans of 20 metres (66 feet) each, weighing 290 tons. River span: Tied arch (crescent-shaped) with platform (single line) below. Tide spans: Girders with parallel flanges and platform on top.

21. *A model of the double line Railway Bridge of the Solingen and Remscheid line over the Wupper Valley at Müngsten* (Emperor William Bridge). — Comp. fig. 103.

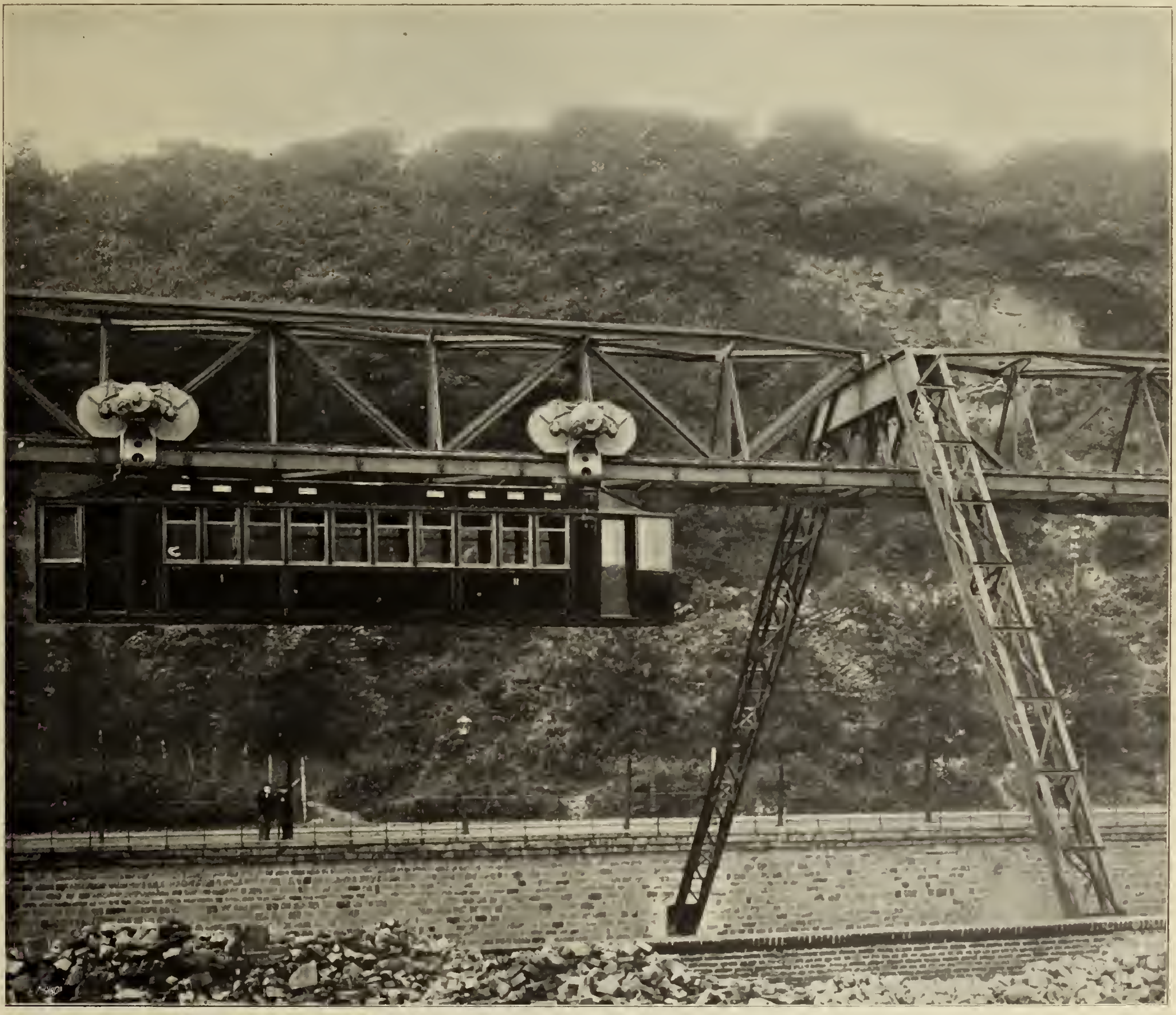
Building Department: Royal Prussian Railway Board at Elberfeld.

Designers and builders: Maschinenbau-Aktien-Gesellschaft Nürnberg, Zweiganstalt Gustavsburg (Nuremberg Engine Works, Ld., Gustavsburg Branch). The firm took the contract for the entire structure, including all earth- and masonry work.

Description: a) *General arrangement and principal dimensions.* The total length of the iron structure amounts to 465,0 metres (1526 feet); width between railings 8,5 metres (27′ 11″); height of rail-level above the Wupper river about 107 metres (351 feet). The superstructure consists of a *central opening* of 170 metres (558 feet) mean span, the extreme span being 180 metres (590 feet), and the adjoining *trestle bridge.* The latter at the Remscheid end has 2 spans of 45 metres (148 feet) each and one span of 30 metres (98 feet), with two trestle piers, each 15 metres (49 feet) long in elevation; at the Solingen end a 45 metres (148 feet) span and 2 30 metres (98 feet) spans with two trestles as before. Above the abutments of the arch there are also trestle piers, 15 metres (49 feet) wide, while at distances of 30 and 15 metres (98 and 49 feet) respectively there are *rocker piers* (provided with flexible connections below and hinged bearings on top), supporting the continuing spans of the trestle bridge.

The centre span consists of a braced arch without hinges. The flanges are 12,21 metres (40 feet) apart at the abutments, 4,0 metres (13′ 1″) at the crown, the mean pitch being about 66 metres (216 feet). The planes of the arch as well as those of the piers are inclined at an angle of 1 in 7, the width of the arch being 5 metres (16′ 5″) on top and 25,685 metres (84′ 3″) near the abutments. All verticals of the arch are stiffened by means of cross bars and bracings. The main windbracing is placed at the bottom flange, being divided at the first node into separate bracings connecting the four bearing points of each abutment. The trestle spans being continued over the entire length of the bridge and supported by roller bearings on top of the piers, are provided with top and bottom windbracings. *The longitudinal (brake-) forces* are taken at three points: at the two end trestles (see fig. 189), which are designed to suit this purpose, and at the crown of the arch. The extension resulting from changes in the temperature is provided for at the piers above the abutments of the arch.

Fig. 186. Electric City Railway Barmen—Elberfeld—Vohwinkel. 1900.

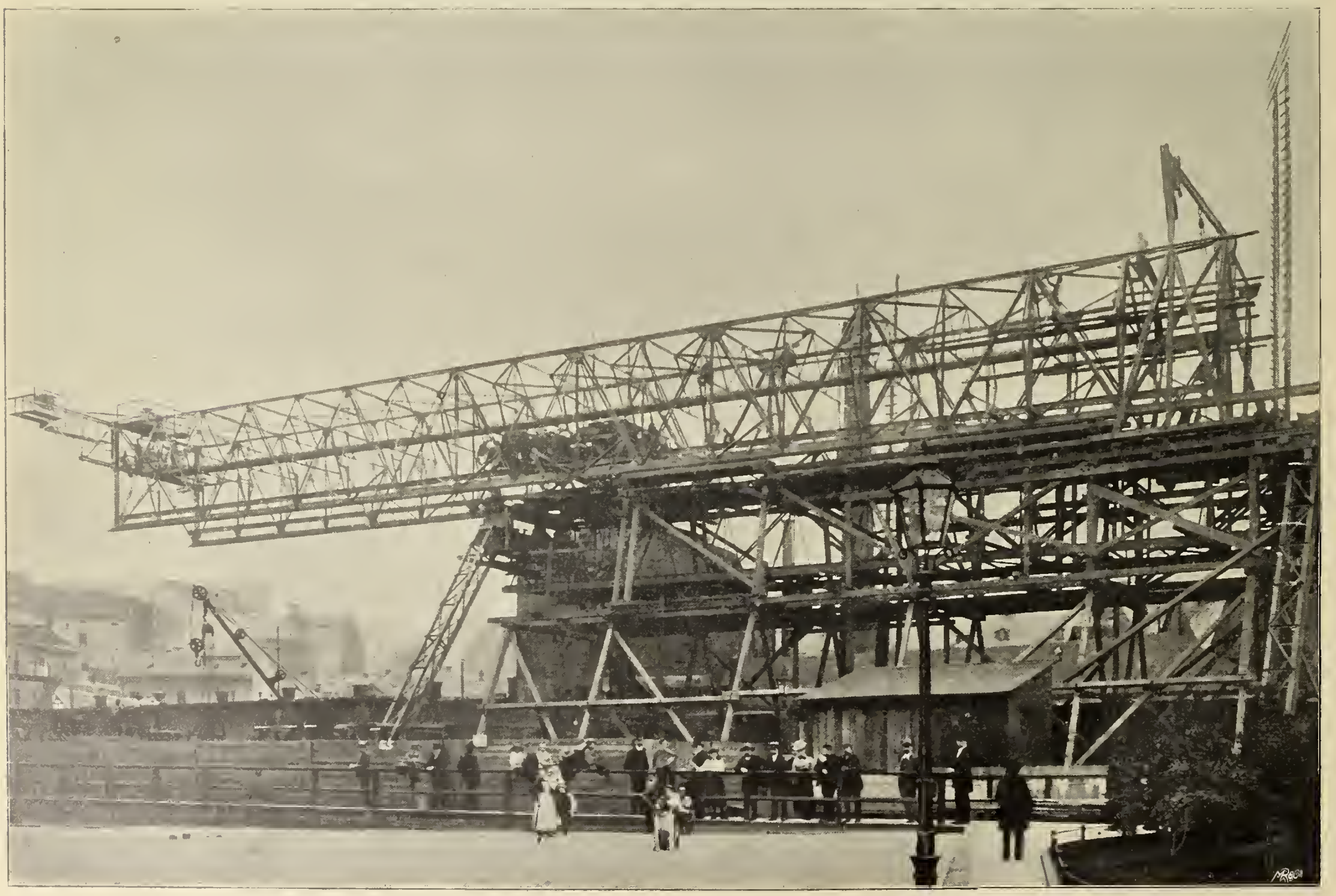


The platform consists of crossgirders and railbearers, both being plategirders. The latter have so-called collision-girders running alongside of them, which support the ends of the cross-sleepers and prevent any breaking through of the wheels in case of derailments. The railbearers, being placed immediately below the rails, are strengthened laterally by means of wind- and cross-bracings. Outside the permanent way a footpath, supported on brackets, runs along.

b) *Material and stresses.* The material consists of basic mild steel of a resistance of 39 to 45 kilos per square millimetre (24,8 to 28,6 tons per square inch) and a ductility of at least 20 per cent, the limit of elasticity being at least 25 kilos (15,9 tons). — *The admissible strain* was fixed as follows: for parts of the platform at 700 kilos per square centimetre (4,445 tons per square inch), for parts not immediately subjected to the impact of rolling loads at 850 kilos (5,40 tons), for parts strained by dead load only, wind-pressure included, at 1250 kilos (7,94 tons). The *shearing*

Fig. 187. Electric City Railway Barmen—Elberfeld—Vohwinkel. Part of the line above the Wupper River. 1900.

Fig. 188. Electric City Railway Barmen—Elberfeld—Vohwinkel. Erecting-girder. 1900.



strain of rivets was assumed at 600 kilos (3,81 tons), their *bearing stress* at 1100 kilos (6,985 tons).

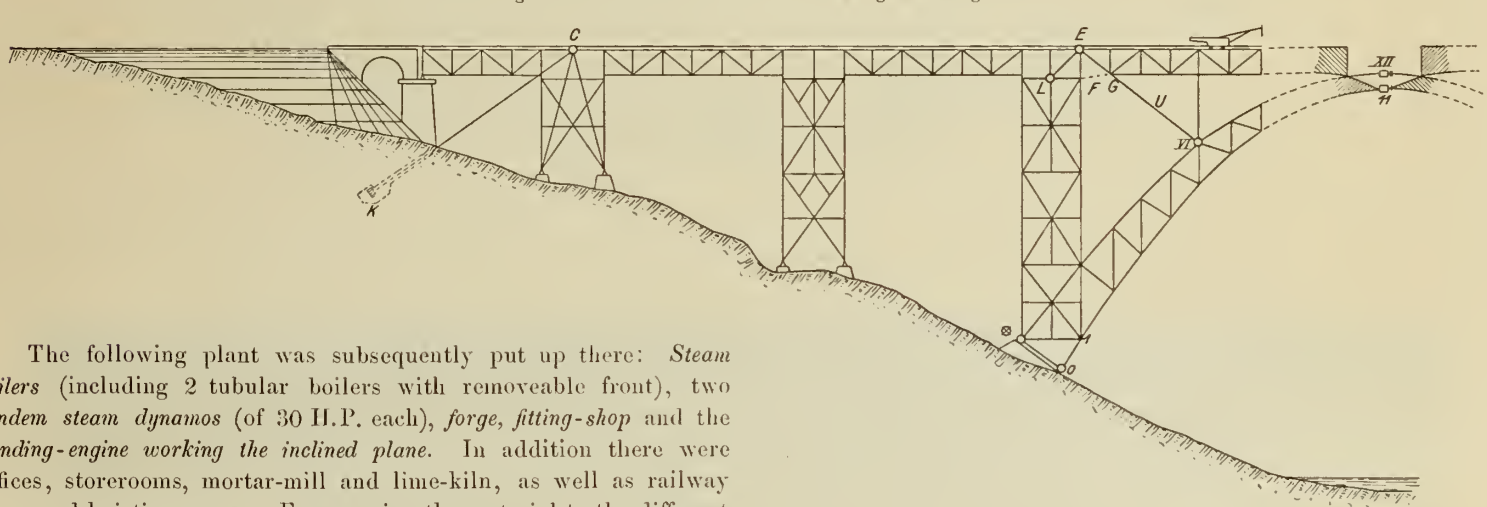
c) *Foundations and piers.* The slopes of the valley immediately below the surface consist of clay-slate, quickly disintegrated by the atmosphere, but getting very solid and reliable in depth. The admissible pressure of the foundations was fixed at 6 to 7 kilos per square centimetre (5,5 to 6,4 tons per square foot).

Coal-bearing sandstone from the banks of the Ruhr and hydraulic lime with a little cement added was used for the masonry work. The facing consists of red Eiffel ashlar, while granite from the Fichtelgebirge was made use of for the bearing stones.

All bearings of the arch and the trestle piers are anchored down to the masonry. The lower bearing plate in case of the piers consists of a circular steel casting, while at the bearings of the arch it is replaced by a system of plategirders and joists. *The whole of the anchor bars are artificially strained.* After the abutment pressures had been determined by the building firm, the working drawings of the piers were prepared by the Royal Railway Board at Elberfeld.

d) *Erection.* At the commencement of the works the railway line from Solingen to the bridge site had been completed, so that by means of earthworks comprising about 10 000 cubic metres (13 100 cubic yards) the Solingen heights could be adapted to form a working yard.

Fig. 189. Erection of the arch of the Müngsten Bridge.



The following plant was subsequently put up there: *Steam boilers* (including 2 tubular boilers with removeable front), two *tandem steam dynamos* (of 30 H.P. each), *forge, fitting-shop* and the *winding-engine working the inclined plane.* In addition there were offices, storerooms, mortar-mill and lime-kiln, as well as railway lines and hoisting cranes. For carrying the material to the different piers each hill was provided with a winding-engine worked by electricity, by means of which specially built cars of 80 centimetres (2′ 7½″) gauge could be raised or lowered by wire rope on an inclined plane with a single line of rail and gradients up to 57 in 100.

A working stage with a double line of rail, about 30 metres (98 feet) high, was erected in the valley, showing a polygonal form in order to be able to approach the centre line of the bridge as near as 8 metres (26′ 3″), and to lift the parts required for building up the arch from it by means of derricks. Besides a pump worked by electricity was put up at the bottom of the valley, by which the underground-water of the Wupper Valley required for mixing mortar and feeding boilers could be raised to the top of the hills on either side. A tank erected at an elevated point served as a reservoir and for equalizing the pressure.

A telephonic service in addition to copper circuits for transmitting the electric power, further the construction of roads and stairs completed the arrangements required for the extensive building operations.

The *erection of the arch* was based on the *cantilever principle,* strong anchorages being made use of for the purpose. The first step consisted in erecting the trestle piers, as well as the girders connecting them, on either slope of the valley, the trestles adjoining the arch (marked E in fig. 189) being the first to be put up, followed by the end piers marked C.

The arch was anchored back by means of the top flange EC of the girder, which is continued without interruption over the entire length of the bridge, together with the anchor bars K, secured to the rocky soil. For this purpose the bar LE was inserted on top of the two piers adjoining the arch and connected to the holding-back ties at E. The tension of the anchor cables — amounting to about 125 tons — was resolved at C into a horizontal component CE and two forces acting in the direction of the foundations of pier C. Length as well as strain of the cables could be regulated and measured at C by means of hydraulic jacks of a capacity up to 300 tons. While the erection of the arch was proceeding, pier C rested on its four bearings up to the time, when the weight of the arch became too large. At that moment its two upper legs were lifted off their bearings and the whole pressure was taken by the lower bearings, round which the pier made a turning movement.

In order to prevent any sagging of the arch, the pier OL, before fixing the ties at E, was turned away from the arch round point ⨯, and point 0 was correspondingly raised by means of suitable supports. In addition bar 0—1 could be strained or put out of strain in any manner desired by hydraulic jacks inserted at point 0, two of them being provided for each bar. In building up the arch the pieces were lifted and fixed by rotary cranes running on the flanges of the top girder, which had been rivetted up in advance. A number of suspended stages made of iron and timber facilitated the erection, rendering the working at the most exposed points safer and more convenient. For the purpose of erecting the central part of the top girder cantilever-fashion, a strong compression member FG had to be temporarily inserted, which as soon as the first rocker-pier at VI with its crossframe, as well as tie U, had been fixed, could be dispensed with.

With this the first stage of the erection was finished. From this time the holding-back structure already described was put into operation, the strain taken by the wire ropes being indicated by the manometers of the hydraulic presses. Only in this manner it was possible to make quite sure of the strains within the system of bars, which at that moment was of double statical indeterminateness. The observations referred to were supplemented by exact calculations; in addition it proved necessary to find out the elastic qualities of the wire ropes used by testing them (see page 80).

The further erection of arch and top girder was accomplished with greater speed, because the pieces to be raised became considerably lighter towards the crown. While the first stage of the erection took about 12 weeks, the second, including the difficult operation of closing the arch, was accomplished within 16 weeks, the whole time required for building up the arch and top girder from the adjoining pier being therefore 7 months.

In order to be able to close the arch at the crown in the manner assumed in the calculations, viz. to make it act as a trebly undetermined system (see also page 71), a temporary hinge was inserted in the bottom flange (at point 11 in fig. 189). By this means the arch, being now supported at the three points ⨯, 11 and ⨯ (see fig. 189) was temporarily made to act as a three-hinged, statically determined structure. In detail this was accomplished in the following manner: Each flange was provided with a hydraulic press at the crown, both together being able to reduce

the pressure in the bottom bars 0—1 to less than 600 tons. By means of the two additional hydraulic presses acting a point 0 (of a total capacity of 600 tons), the remaining strain could be taken out of the bars, which subsequently no longer formed part of the system.

After taking off the pressure at the crown, as well as relieving the holding-back cables, the joint of the bottom flange at 11 could be closed by fitting in a steel casting of suitable shape. Subsequently the hydraulic press at XII together with the cables and the tension members U could be removed, with the result that from

Earthworks and blasting, about 21 000 cubic metres (27 500 cubic yards).

Masonry work, about 11 000 cubic metres (14 400 cubic yards).

Date of erection: In July 1893 work was commenced by getting the working yards ready, subsequently erecting the stage down in the valley, building the inclined plane, etc., the whole of these preliminary works being completed by April 1894.

Excavating was commenced at the end of February, masonry work on May 1, 1894. The whole of the foundations, including

Fig. 190. La Galera-Viaduct of the Great Venezuela Railway. 1893. (Dimensions in metres).

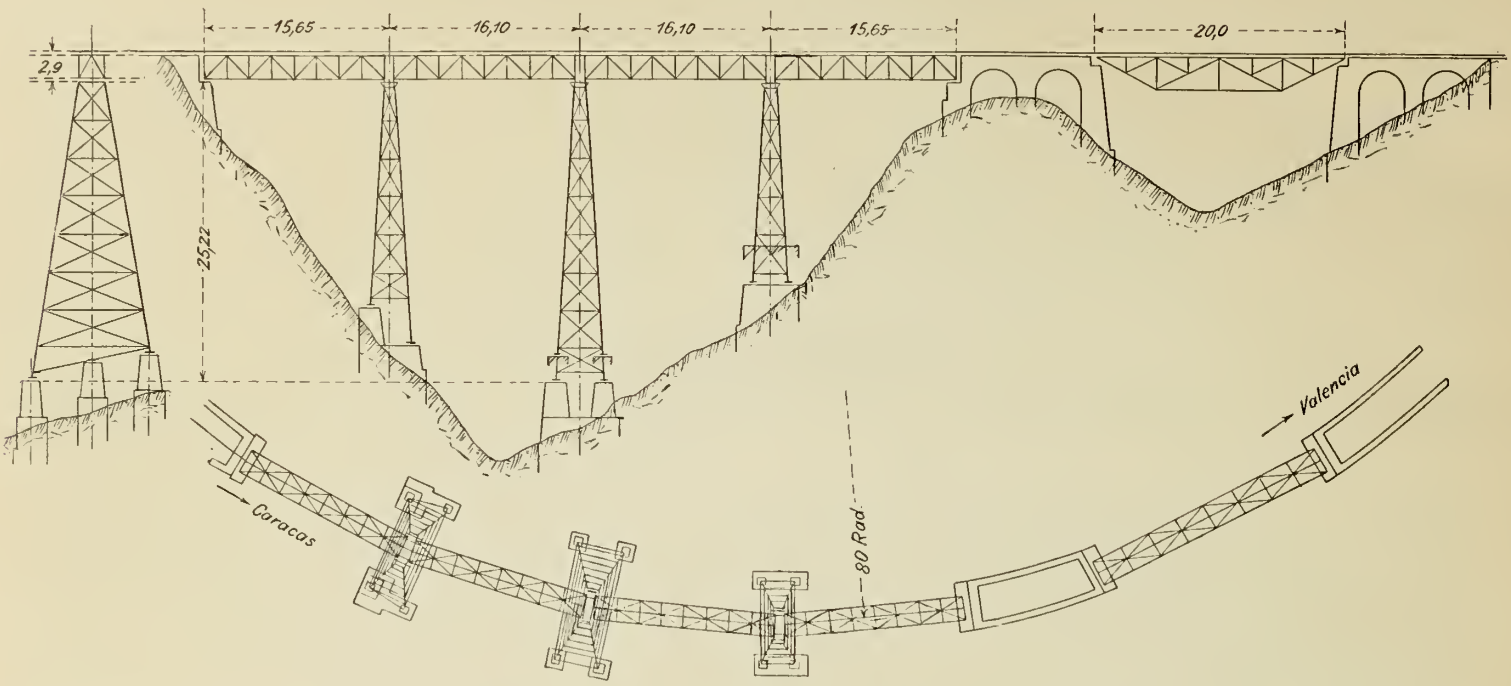
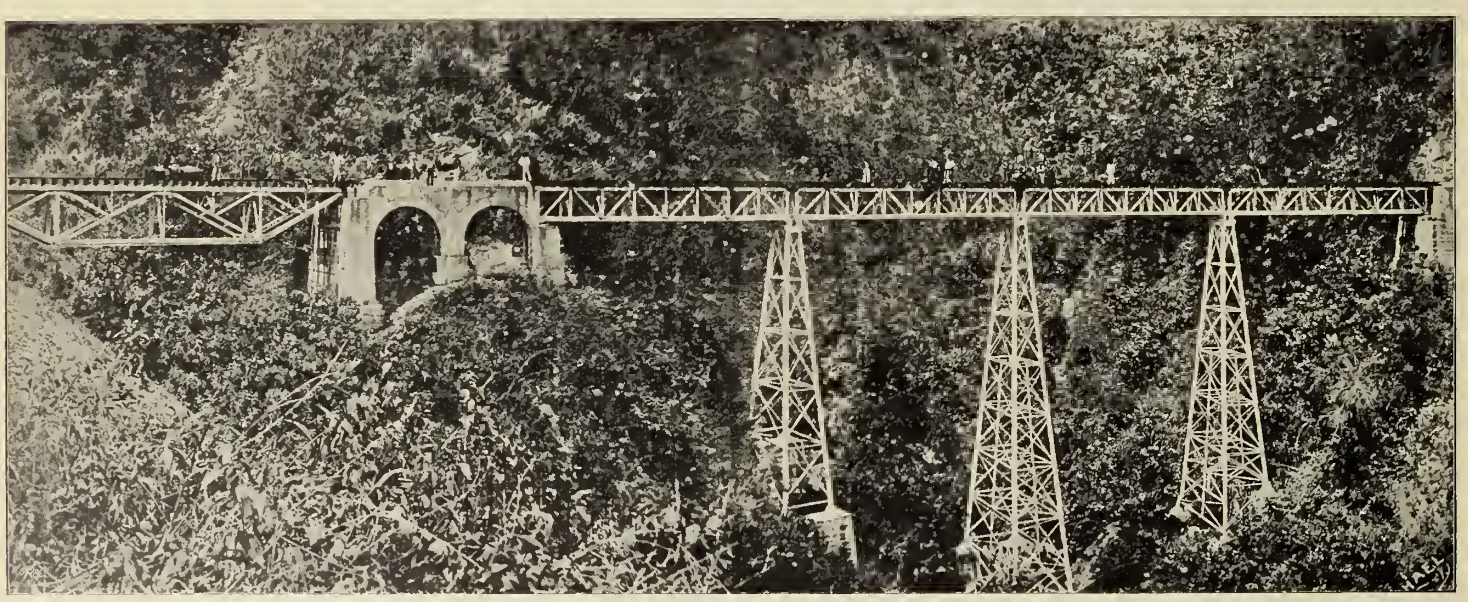


Fig. 191. La Galera-Viaduct of the Great Venezuela Railway. 1893.



this moment the structure formed a three-hinged arch, supported at the crown (point 11) and at the two points marked ⌘ of the springing.

Incidentally it was found that, assuming the actual load of the arch (including stages, cranes, etc.), the strain in the top flange of a two-hinged arch, supported at points ⌘ of the springing, would be practically nil. For this reason the bars of the top flange, opposite point 11, could now be fixed without any initial strain.

In order, therefore, to bring about the final state of the arch, viz. that without hinges, it only remained to insert the bars 0—1 and provide them artificially with their proper strain, as calculated, by applying the hydraulic presses. After finally the ball-bearings required there had been fixed by wedges, the erection of the arch was practically finished. For further particulars compare Rieppel's paper on the subject[94]).

c) *Weights and quantities.* The weight of the entire iron structure, including anchorages, amounts to 5100 tons.

the anchorages, were finished in July 1895. The erection of the ironwork was commenced during the spring.

The arch was closed on March 22, 1897, and to celebrate this event (the day happening to be the 100th birthday of emperor William I) the bridge received the official name of "Kaiser Wilhelm-Brücke" (Emperor William Bridge).

On July 15, 1897, the bridge was opened for traffic, after it had been tested in a most elaborate manner.

VI. Gesellschaft Union (Union Company) at Dortmund.

22. *New Bridge Workshops of the Union Mining, Iron and Steel Company, Ld., at Dortmund.* 1 coloured perspective, 5 drawings and 2 photographs.

Owners, designers and builders of the ironwork: The Union Company at Dortmund.

For Description and details see page 111 and figures 167 to 171.

23. *La Galera Viaduct of the Great Venezuela Railway.* 1 photograph. — Comp. figures 190 and 191.

Owners: The Great Venezuela Railway Company.

Designed by the same Company.

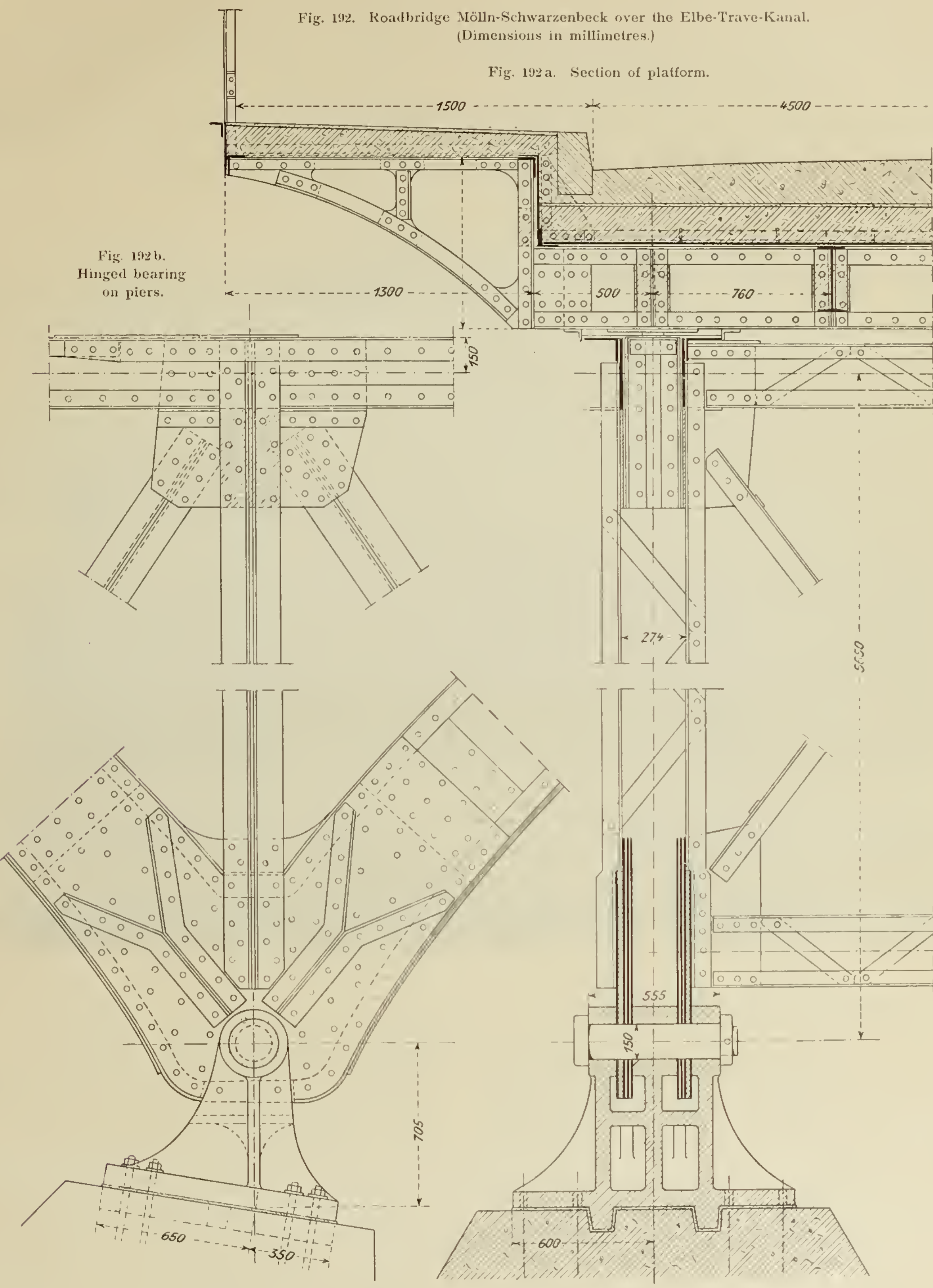
smaller part, 20 metres (65′ 7″) long, being separated from the main viaduct by a long arched abutment, forms a deck span with two main girders, 2.2 metres (7′ 3″) apart, with a railbearer put in between their horizontal top flanges.

On account of the very unfavourable conditions of transport the pieces forming the bridge had to be limited in weight to 0,35 ton each, the same state of things prevailing at all other

Fig. 192. Roadbridge Mölln-Schwarzenbeck over the Elbe-Trave-Kanal. (Dimensions in millimetres.)

Fig. 192a. Section of platform.

Fig. 192b. Hinged bearing on piers.



Builders of the ironwork: The Union Works.

Date of erection: 1893.

Description: The bridge is situated in a curve of 80 metres (262 feet) radius, and being divided by a ridge jutting out into the ravine, consists of two parts of a different character.

The larger part, viz. the viaduct proper, 64 metres (210 feet) long and about 35 metres (115 feet) high above the bottom of the valley, consists of four iron spans of 16 metres (52′ 6″) each, supported by concrete abutments and three iron piers. The bridges of the same line. In order to facilitate the erection all parts not yet rivetted up at the works were joined together by means of conical bolts.

The total weight of the ironwork amounts to about 120 tons.

24. *Bridge carrying the high road from Mölln to Schwarzenbeck over the the Elbe-Trave Canal.* 1 photograph. See figures 51 and 192.

Building Department and designers: The Canal Commission at Lübeck.

Builder of the ironwork: The Union Company.

Date of erection: 1897.

Description: The structure forms a cantilever bridge of three spans, the centre span being 32,25 metres (105′ 10″) wide between the hinges and the side spans 13,7 metres (44′ 11½″) each. The platform consists of a macadamized roadway, 4,5 metres (14′ 9″) wide, with a footpath, 1,5 metres (4′ 11″) wide, on either side. The weight of the ironwork amounts to 153 tons.

a) Left-hand side.

25. *Station Roof of the Railway Terminus at Cologne.* 1 coloured perspective, 5 drawings and 2 photographs.

Building Department: Royal Railway Board at Cologne.

Designed by the Building Department.

Fig. 193. Union Works. Bridge over the Serajoe on Java. 1897.

Builders of the ironwork: The Union Company.

Date of erection: The hall was erected in 1892 and 1893 with the aid of a travelling iron stage weighing about 140 tons, without any interruption of the railway traffic.

Description: The station hall, being 92 metres (302 feet) wide and 255 metres (837 feet) long over all, covers an area of about 22 200 square metres (239 000 square feet). It consists of three spans, all covered in with galvanized corrugated iron, viz. a centre span of 63,9 metres (210 feet), 24 metres (79 feet) high, and two small side spans of 13,4 metres (44′ 0″) each. The principals, 8,5 metres (27′ 11″) apart between centre lines, are two-hinged arches with crossed diagonals, each consisting of two arched girders, 0,8 metre (2′ 3″) apart, joined together by cross bracings at top and bottom. Alternate panels of the roof are provided with a windbracing, with the exception that near the screens three adjoining panels are braced together to form an efficient windgirder. The side roof principals are tied plate-arches with hinges at the springing. The purlins are designed on the cantilever principle and are moveable in a longitudinal direction.

The halls are *lighted* by sky-lights (of the ridge and furrow-system) on top of the centre nave, in addition to vertical windows, 7 metres (23 feet) high, above the side spans. 1600 square metres (17 220 square feet) of open roof area are provided for the purpose of *ventilation.* Both ends of the building are closed by glazed screens. The *total iron weight* of the hall, excluding the corrugated iron covering, comes to 3200 tons, being 145 kilos per square metre (244 lbs. per square yard) of roofed-in area.

26. *Railway- and Roadbridge over the Vistula at Graudenz:* 1 photograph. — Comp. fig. 89.

Building Department: Royal Railway Board at Bromberg.

Designed by the Building Department.

Builders of the ironwork: The Union Company.

Date of erection: 1876 to 1879.

Description: The bridge consists of 11 spans of 97,3 metres (319 feet) each, the semiparabolic maingirders being 11,536 metres (37′ 10″) apart between centre lines.

The platform is formed of longitudinal and crossgirders, carrying the sleepers and rails of the railway line as well as the timber beams and planking of the roadway.

Windbracings are provided between the top and the bottom flanges of the maingirders.

Total weight of iron 8240 tons.

27. *Roadbridge over the Dortmund-Ems Canal at Münster, Westfalia.* 1 photograph.

Building Department: Royal Canal Commission at Münster.

Designers and builders of ironwork: The Union Company.

Date of erection: 1896.

Description: The bridge has a span of 34,72 metres (114 feet). The roadway, 6 metres (19′ 8″) wide and a footpath, 1,2 metres (3′ 11″) wide, are placed between the maingirders, which are 7,95 metres (26′ 1′) apart, while a second footpath, 2,5 metres (3′ 3″) wide, is outside the maingirder on the side adjoining the roadway.

The iron structure consists of a tied braced arch with 2 hinges. The platform, 6 metres (19′ 8″) wide, is formed of buckled plates, carrying the road metalling on concrete. The inside footpath has

a covering of asphalte on concrete, carried by galvanized corrugated iron, while the outside footpath has 6 centimetres ($2^3/_8''$) of planking. The wind- and crossbracings consist of: 1. crossframes at each panel of the arch, 2. a windgirder between the top flanges, supported by the two portals, which, being designed as braced arches with two hinges, transmit the windpressure immediately down to the fixed bearings.

The weight of the ironwork amounts to 170 tons.

b) Right-hand side.

28. *Single line Railway Bridge over the Serajoe near Poerworedjo on Java.* 1 coloured perspective, representing the bridge during erection, and 5 drawings. See fig. 193.

29. *Roadbridge over the Elbe at Magdeburg.* 1 coloured perspective and 6 drawings. — Compare figures 111, 112, 194 and 195.

Owners: The Madgeburg city authorities.

Designers: The Union Works at Dortmund; Phil. Holzmann & Co., Ld., of Frankfort-on-Main; Mr. Eberlein, architect, of Cologne.

Builders: Philipp Holzmann & Co. of Frankfort-on-Main for pneumatic foundations, piers and buildings above piers; the exhibiting firm for the ironwork.

Date of erection: 1900 to 1901.

Description: The bridge consists of a river span, 135 metres (443 feet) wide, and side spans of 28,5 metres (93′ 6″) each (masonry arches) at either end.

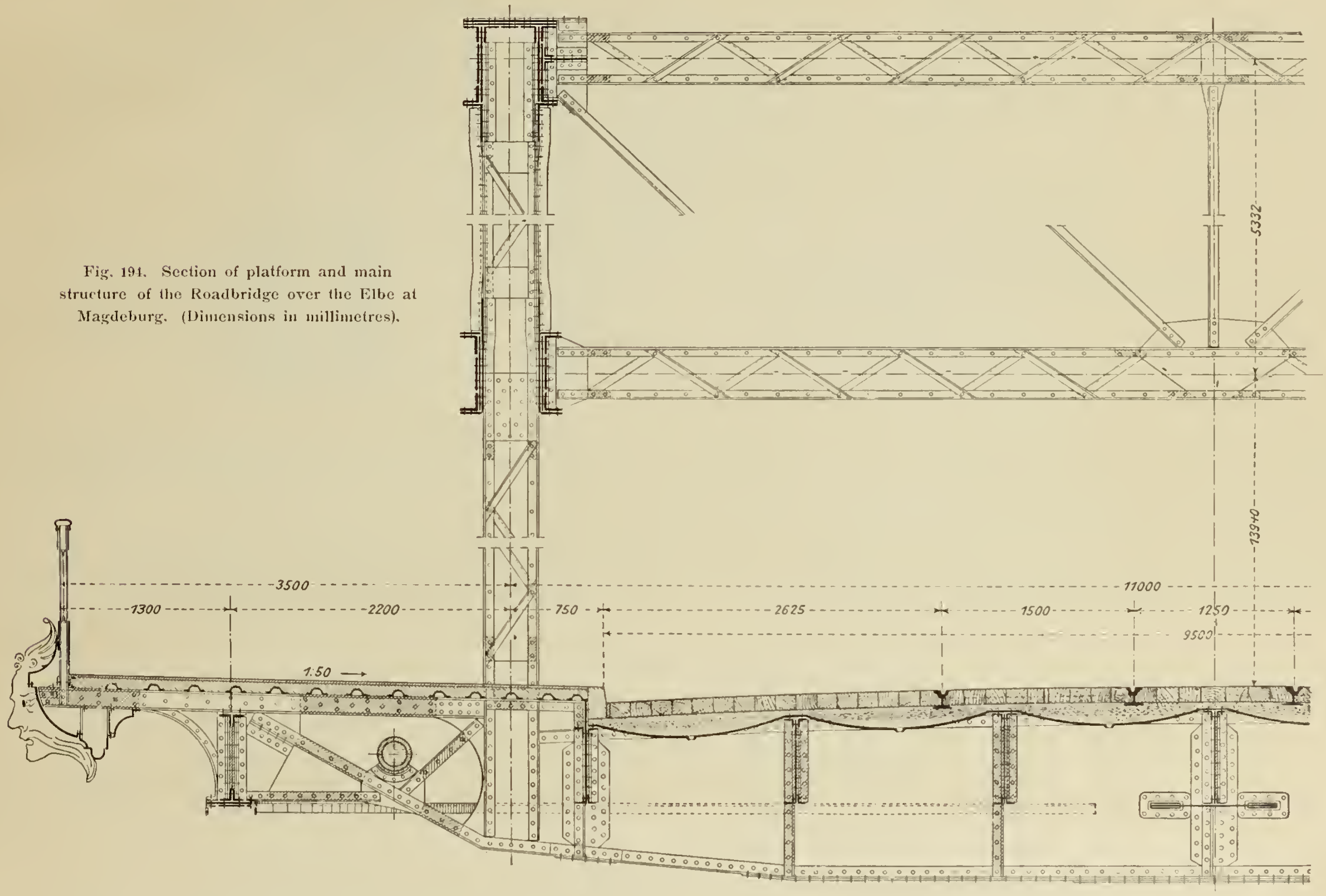


Fig. 194. Section of platform and main structure of the Roadbridge over the Elbe at Magdeburg. (Dimensions in millimetres).

Owners: Serajoedal Stoomtram Maatschappy, at 'sGravenhage.

Designed and built by the Union Company.

Date of erection: 1897.

Description: The maingirders of the bridge, being continuous over the two spans of 40 metres (131 feet) each, have parallel flanges and a double set of diagonals, the platform being on top. There is an upper as well as a lower windbracing, both acting as continuous girders on three supports. In addition cross frames, 3,333 metres (10′ 11″) apart, are provided.

The rapid river often carrying along trunks of trees and masses of debris, it was considered risky to erect any fixed scaffolding within the river bed. The iron structure was therefore put together on shore and hauled into position over the centre pier with the aid of a headpiece, 10 metres (32′ 9″) long. This manner of erection is particularly suitable in case of deckbridges, because the platform girders need be fixed only after the bridge is in position.

The *weight* of the ironwork of the bridge amounts to 140 tons.

The main arches, 11 metres (36′ 1″) apart between centre lines, support the platform, 9.5 metres (31′ 2″) wide, consisting of a roadway with two tramway lines, showing a gradient of 1 in 70. The footpaths outside the main arches are 3,2 metres (10′ 6″) wide each.

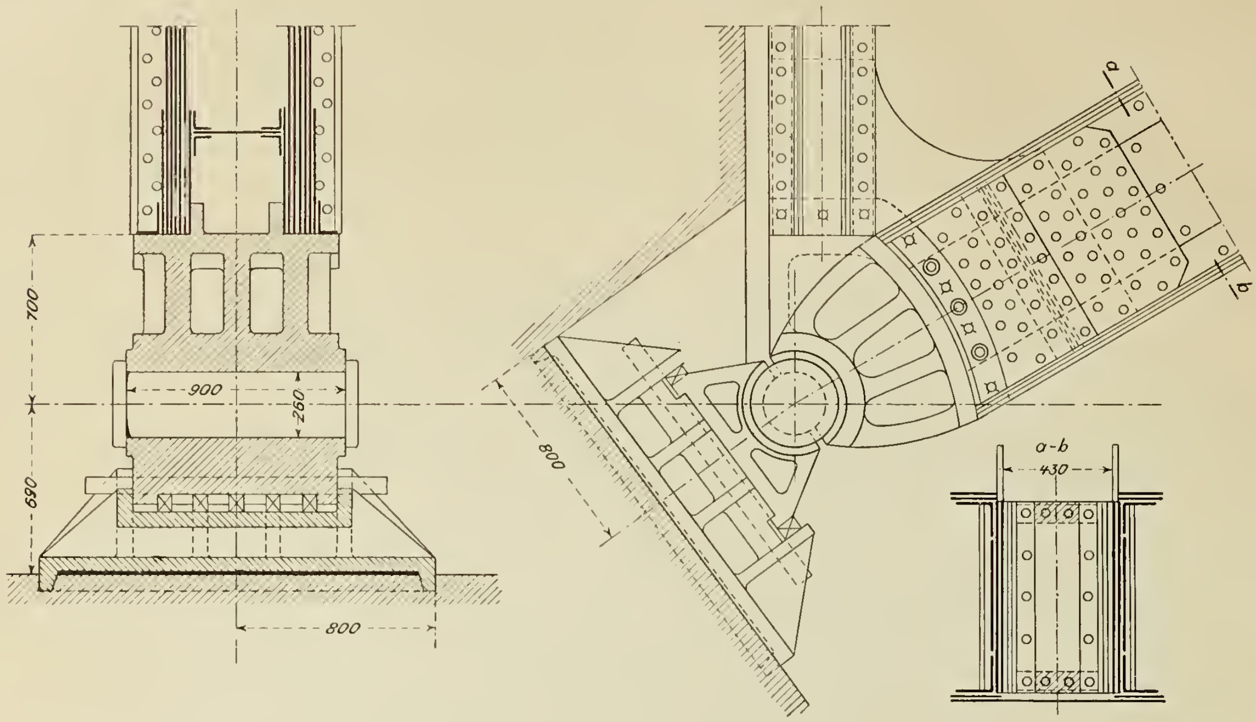
The main span consists of braced arches with hinges at the springing. The crossgirders, 7,5 metres (24′ 8″) apart, are suspended from them by vertical ties, which are connected to the bottom flange of the main arch in a manner allowing longitudinal deformation. For further details compare fig. 194. The platform is formed of buckled plates, carrying the wood pavement, 12 centimetres ($4^3/_4''$) thick, on concrete. The footpaths have a covering of 2 centimetres ($^3/_4''$) of asphalte on 8 centimetres (3″) of concrete and iron flooring.

In order to provide for any extension of the platform resulting from changes in temperature, all longitudinal girders have moveable (rocker-) bearings on the last crossgirder but one. The latter as well as the end crossgirder is firmly rivetted up with the main structure, while all remaining crossgirders are suspended from the arch by tension members, connected to its bottom flange in a flexible manner.

There are two *windbracings*, one below the platform, the other between the top flanges of the arch, the former being designed in a manner allowing it to move perfectly independently of the main structure. For this reason the lower windgirder has been rivetted up with the platform at its central part, being consequently, together with the latter, free to move in a longitudinal direction.

The windbracing between the top flanges of the arch is supported by the portal frames, which transmit the wind pressure down to the fixed bearings (see fig. 195). In addition all verticals are provided with cross frames for stiffening the main structure. The two portals have an arched top member, their bottom part being represented by the end cross girder.

Fig. 195. Hinges of the Roadbridge over the Elbe at Magdeburg.
(Dimensions in millimetres.)



At the last but one crossgirder the flanges of this windgirder are butting against corresponding part of the crossgirder, the planed surfaces being parallel to the centre line of the bridge. From these sliding bearings the flanges of the end panels finally converge to one point over the pier, where they are supported in a manner allowing them to move in a longitudinal direction.

The *weight* of the ironwork contained in the river span amounts to 950 tons.

30. *A number of photographs,* representing *the Roadbridge over the Elbe at Magdeburg,* just described, and *the Railway Bridge over the Serajoe on Java.*

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Printed by Gustav Schade (Otto Francke), Berlin N.